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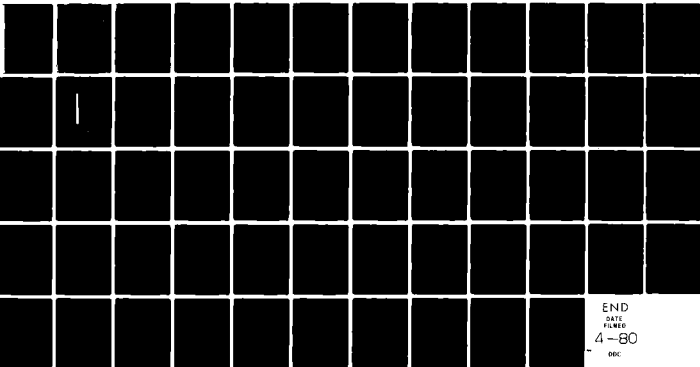
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9 TECHNICAL REPORT
7694-1

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MODEL TESTS AND ENGINEERING
STUDIES OF THE SWATH VII SMALL
WATERPLANE AREA TWIN-HULL SHIP.

By

10) Karl L./Kirkman, B. J./Young
J. W./Kloetzli P./Majumdar

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 7694-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Model Tests and Engineering Studies of the SWATH VII Small Waterplane Area Twin-Hull Ship (U)		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Karl L. Kirkman et al		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hydronautics, Incorporated Laurel, Maryland		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE 63534 N Proj. SS1415
11. CONTROLLING OFFICE NAME AND ADDRESS CNO (OP96V) Washington, D.C. 20350		12. REPORT DATE November 1976
		13. NUMBER OF PAGES 125
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) DTNSRDC Bethesda, Maryland 20084		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Unlimited and approved for Public release.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Advanced Naval Vehicle Concepts Evaluation ANVCE Technology Assessment SWATH Ship		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The main objective of this effort is to obtain drag data and wake data for the SWATH VII Form, and using this data to obtain estimates of the required propulsive horsepower for the design displacement of 4355 metric tons. A secondary objective was to determine the stern pitch fin settings for minimum drag and, to do this, drag tests were performed for three speeds and a range of fin angles.		

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ADMINISTRATIVE INFORMATION

HYDRONAUTICS, Incorporated was authorized (Reference 1) to carry out a program of model tests and related engineering studies of the resistance and propulsion characteristics of a Small Waterplane Area Twin Hull Ship (SWATH) for DTNSRDC, Code 117. This work was sponsored as part of the Task IVA effort by the Advanced Naval Vehicles Concepts Evaluation Project Office (OP 96V). Funding was provided under Program Element Number 63534 N, Project Number SSH15.

INTRODUCTION

The experimental program consisted of resistance (EHP) tests of SWATH VI-A fully appended, resistance (EHP) tests of SWATH VII with and without appendages, a wake survey of SWATH VII fully appended at a speed corresponding to 20 knots full scale, and resistance tests of SWATH VII with various stern fin deflections. The calculations included a design study of alternative wake adapted propellers, and estimates of propulsive performance under certain extraordinary machinery operating conditions.

This report presents the results of the model tests and the calculation of propulsive performance.

BACKGROUND

The main objective of this effort is to obtain drag data and wake data for the SWATH VII Form, and using this data to obtain estimates of the required propulsive horsepower for the design displacement of 4355 metric tons. A secondary objective was to determine the stern pitch fin settings for minimum drag and, to do this, drag tests were performed for three speeds and a range of fin angles.

In addition, in order to obtain direct comparisons between the drag of SWATH VI-A and VII; a drag test of VI-A as received was performed using test procedures consistent with those for SWATH VII.

Description of Ship and Model

A scale model of the SWATH VI-A was furnished to HYDRONAUTICS, Incorporated by DTNSRDC. The scale ratio for this configuration was 22.5:1. The geometric characteristics of the ship and model, designated 7694-1, are given in Table 1. The parameters which most strongly influence drag characteristics are the hull length-to-diameter ratio of 16.0, the strut waterplane area coefficient of 0.85 and the strut maximum thickness of 0.098 meter.

At the conclusion of the comparative drag test of SWATH VI-A, the model was modified to a configuration designated SWATH VII in accordance with instructions from DTNSRDC. The modifications are detailed in the drawings included in Appendix A. The model modifications consisted of lengthening the sidehulls, manufacturing new struts, and fitting these parts to the cross-structure at a

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Table 1
Geometric Characteristics of Ship and
Model 7694-1

Characteristic	SWATH VI-A Ship	Model 7694-1
Linear Scale Ratio		22.5
Length, Hull, Meter	74.20	3.298
Diameter, Hull, Meter	4.57	0.203
Length, Strut, Meter	52.52	2.334
Spacing, C_L to C_L of hulls, Meter	22.86	1.016
Draft, Meter	8.13	0.361
Trim, Meter	0	0
Displacement, Metric Tons, kgs	2922	249.52
Wetted Surface:		
Sidehulls and Struts, M^2	2534.62	5.007
Bow Pitch Fins, M^2	34.524	0.0682
Stern Pitch Fins, M^2	100.93	0.1994
Prismatic Coefficient, Hull	0.85	0.85
Thickness, Strut, Meter	2.21	0.098
Waterplane Area Coefficient, Strut	0.85	0.85

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slightly increased spacing between sidehulls. The characteristics of this configuration, designated Model 7694-2, are given in Table 2. Photographs of the model are given in Figure 1. Of these changes, the parameter mainly responsible for the greatly improved wavemaking characteristics that were measured was the new hull length-to-diameter ratio of 20. The new strut had a slightly reduced maximum thickness of 0.095 meter, but the waterplane area coefficient remained at 0.85.

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Table 2
Geometric Characteristics of Ship and
Model 7694-2

Characteristic	SWATH VII Ship	Model 7694-2
Linear Scale Ratio		24.0
Length, Hull, Meter	97.54	4.064
Diameter, Hull, Meter	4.877	0.203
Prismatic Coefficient, Hull	0.88	0.88
Length, Strut, Meter	66.59	2.776
Thickness, Strut, Meter	2.286	0.095
Waterplane Area Coefficient, Strut	0.85	0.85
Spacing, C_L to C_L of Hulls, Meter	27.13	1.130
Draft, Meter	8.67	0.361
Trim, Meter	0	0
Displacement, Bare Hull, Metric Tons, kgs	4355	N.A.
Wetted Surface:		
Sidehulls and Struts, M^2	3568.3	6.195
Rudders, M^2	103.6	0.180
Bow Pitch Fins, M^2	39.28	0.068
Stern Pitch Fins, M^2	114.84	0.199



FIGURE 1 - PHOTOGRAPH OF SWATH VII, MODEL 7694-2

MODEL TEST PROGRAM

This section of the report describes the test equipment and presents the test results expanded to ship form.

Test Apparatus and Procedures

The experiments were conducted in the HYDRONAUTICS Ship Model Basin (HSMB) which is described in detail in Reference 2. The basin is 420 ft in length, 25 ft wide, and 13 ft deep.

Drag (EHP) Tests

By mutual agreement with DTNSRDC, the drag tests were conducted with the model at zero trim to facilitate correlation with the analytic drag predictions. Further, for the VI-A tests the model was free in heave, but for the VII tests the model was fixed in heave to facilitate testing with numerous pitch fin settings.

In both cases, model drag was measured using standard 4-inch variable reluctance force "block gages."

Wake Survey

The wake survey test to determine the longitudinal, radial and tangential velocity components in the propeller plane was made using a pitot-static yaw head rake. The rake was 4 pitot probes fixed at radial positions of 1.5, 2.7, 3.9 and 5.1 inches model scale from the propeller shaft centerline and is fixed to a shaft supported by the stern tube bearings. The rake was placed so that the probe tips lie in a typical propeller plane,

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and rotated in angular position.

The outputs from the pitot tubes were measured by pressure transducers which were connected to the rake by flexible tubing. The rake/transducer assembly was precalibrated, and check cals were made on the individual transducers.

The wake survey was conducted at the 8.67 meter draft for SWATH VII at 20 knots with rudder, bow pitch fin and stern pitch fins all set at nominal zero deflection (parallel to the craft lower-hull centerline). The test measurements were made at 15-degrees radial spacings throughout the 360-degree propeller disc.

REDUCTION AND PRESENTATION OF RESULTS

The data obtained from the various tests have been reduced in accordance with accepted practice as described in detail in the following sections. The predictions are presented in appropriate graphical or tabular form to provide the required information about the ship's performance.

Resistance Characteristics

The resistance data were expanded to ship values using the Froude hypothesis: C_R model equals C_R ship, the ITTC correlation coefficients, and a correlation allowance of 0.0005 specified by DTNSRDC. In computing the frictional resistance of the model and ship, the bow and stern pitch fins were treated as separate surfaces, and the rudders for SWATH VII were considered as an extension of the strut for purposes of calculating their specific friction resistance. A breakdown of the ship wetted surface components is given in Table 3 as used for expanding model data.

The predicted ship EHP values are given in Figure 2 for SWATH VI-A Appended in Figure 3 for SWATH VII Bare Hull, and in Figure 4 for SWATH VII Appended. The EHP values are tabulated in Tables 4, 5 and 6.

Actual test data spots reduced to residuary resistance coefficient, C_R , form are given in Appendix B for further analysis by others.

For the tests with varying stern pitch fin angle, the EHP results are given in Figure 5. This figure shows the variation in EHP with fin angle for three speed contours, $V_K = 16, 18$ and 20 knots.

Table 3
Ship Wetted Surface Components as Used
for Expanding Model Data

Configuration	Item	Wetted Surface M ²	Characteristic Length, M
SWATH VI-A (Model 7694-1)	Lower Hull	1.7187	3.297
	Strut	0.7846	2.334
	Bow Pitch Fin	0.0341	0.117
	Stern Pitch Fin	0.0997	.201
	Total Wetted Surface, $\Sigma \times 2$	<u>5.2742</u>	--
SWATH VII Barehull (Model 7694-2)	Lower Hull	2.1619	4.148
	Strut	.9356	2.776
	Total Wetted Surface, $\Sigma \times 2$	<u>6.1950</u>	--
SWATH VII Appended (Model 7694-2)	Lower Hull	2.1619	4.148
	Strut/Rudder	1.0255	3.019
	Bow Pitch Fin	0.0341	.117
	Stern Pitch Fin	0.0997	.201
	Total Wetted Surface, $\Sigma \times 2$	<u>6.6424</u>	--

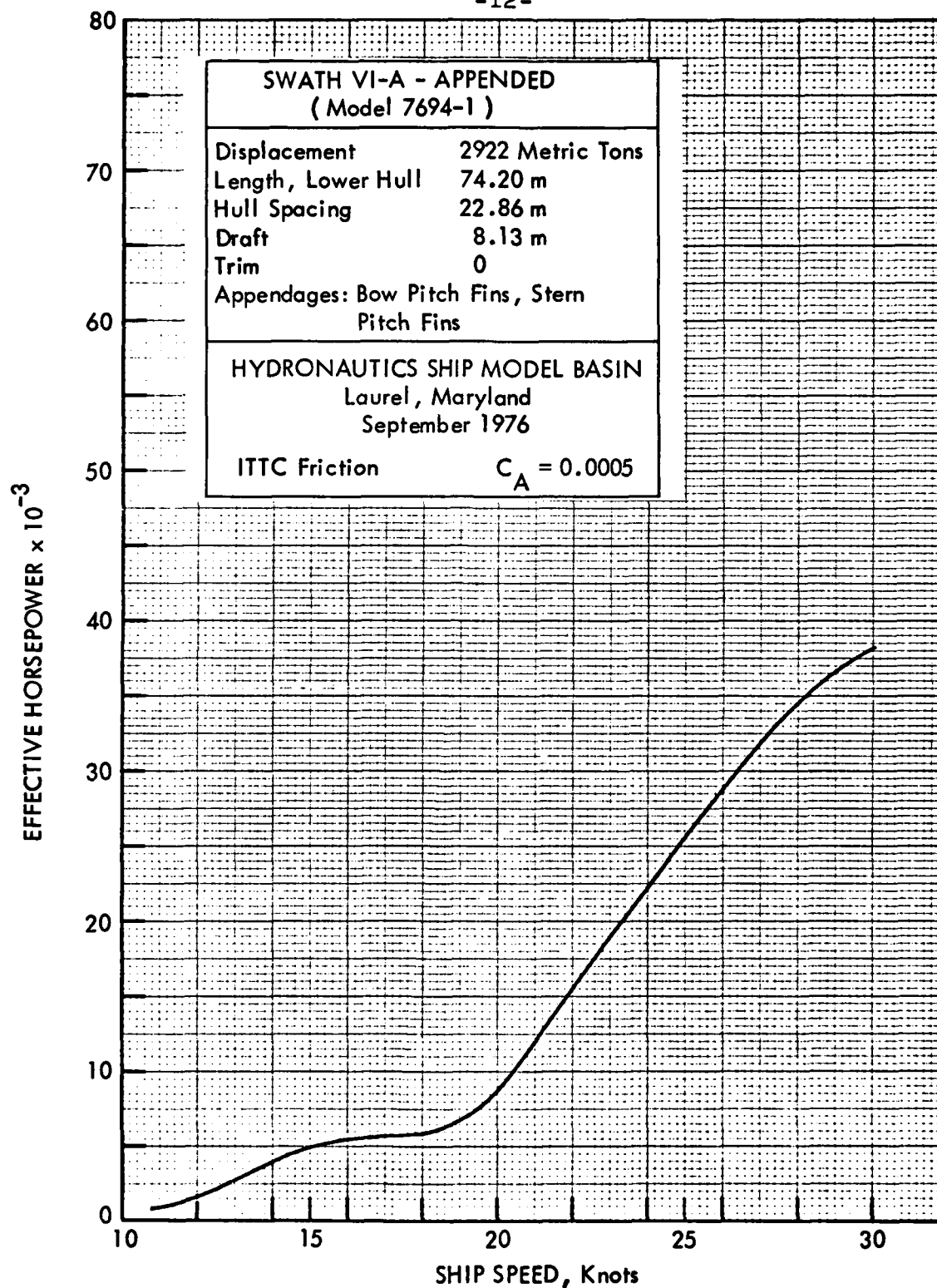


FIGURE 2 - PREDICTED EHP FOR SWATH VI-A - APPENDED

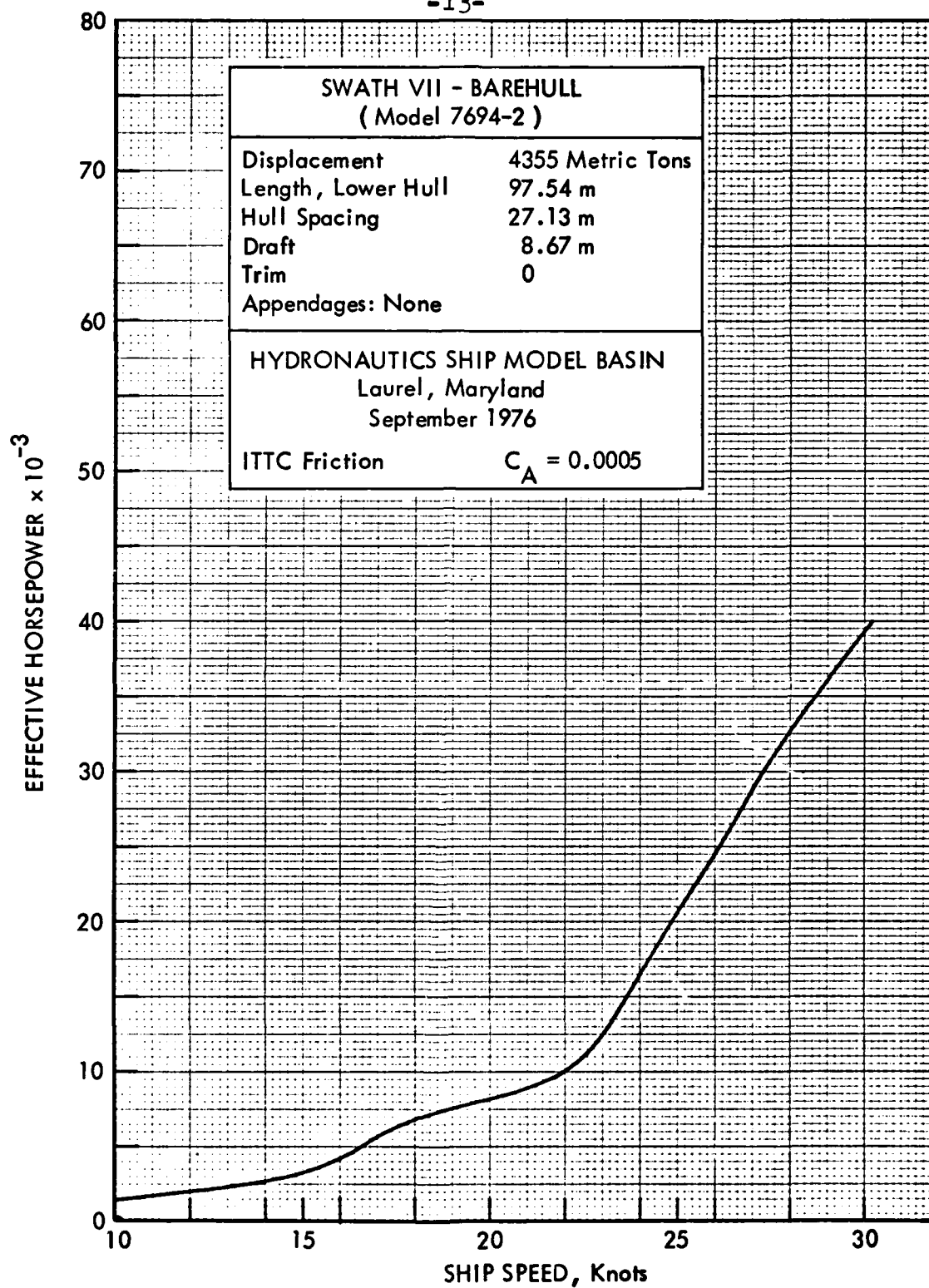


FIGURE 3 - PREDICTED EHP FOR SWATH VII - BARE HULL

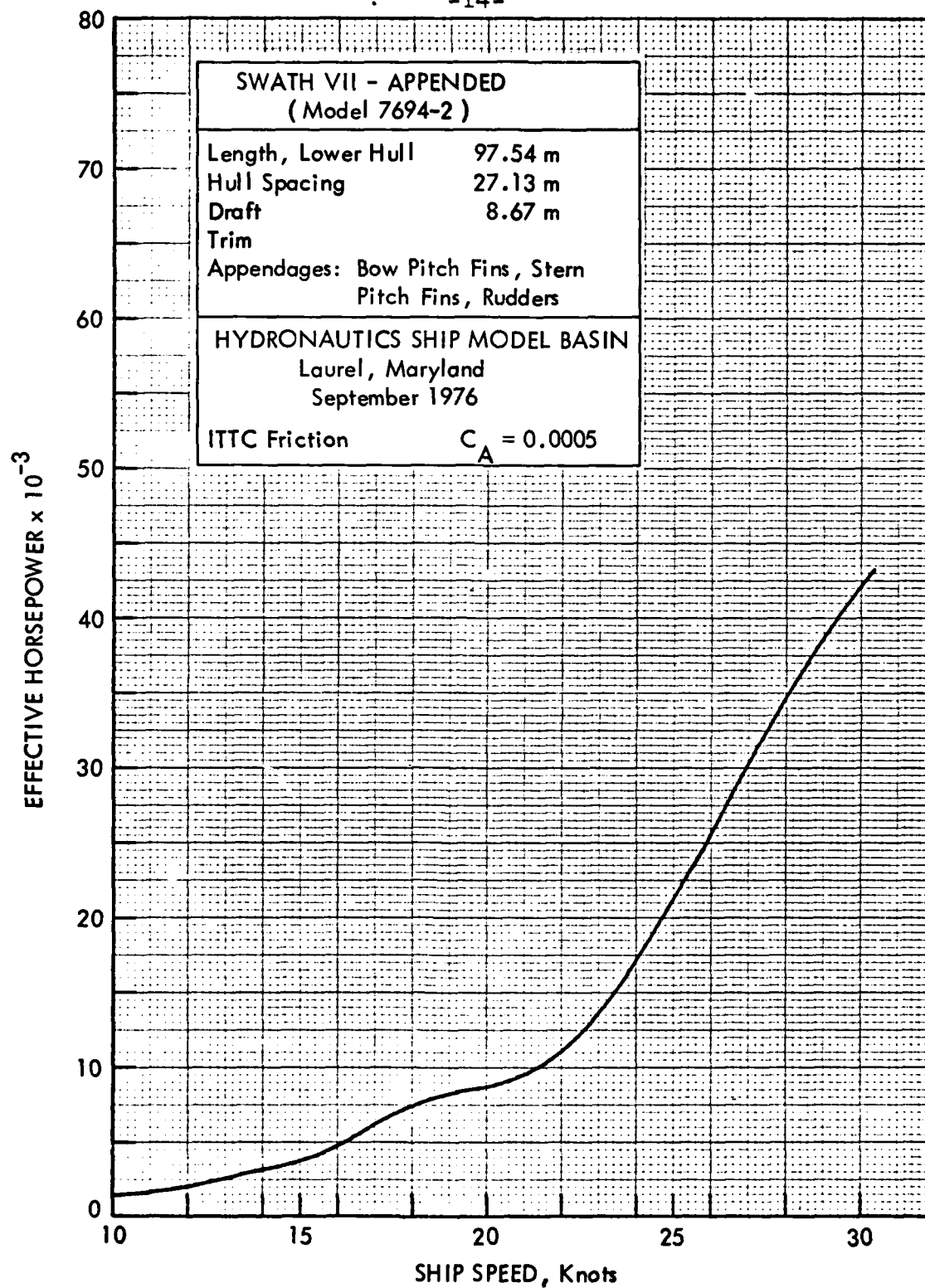


FIGURE 4 - PREDICTED EHP FOR SWATH VII - APPENDED

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Table 4
Effective Horsepower for SWATH VI-A
Appended at a Displacement of
2922 Metric Tons

V_K	EHP
12	1,707
14	3,512
16	5,311
18	5,789
20	8,977
22	15,572
24	22,171
26	28,634
28	34,580
29	36,750

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Table 5
Effective Horsepower for SWATH VII
Bare Hull at a Displacement of
4355 Metric Tons

V_K	EHP
10	1,097
12	1,803
14	2,643
16	4,277
18	6,854
20	8,140
22	10,287
24	16,695
26	24,611
28	32,624
30	39,833

Table 6
Effective Horsepower for SWATH VII
Appended

V_K Knots	EHP
10	1,169
12	1,988
14	3,104
16	4,631
18	7,518
20	8,615
22	11,107
24	17,342
26	25,832
28	35,163
30	42,850

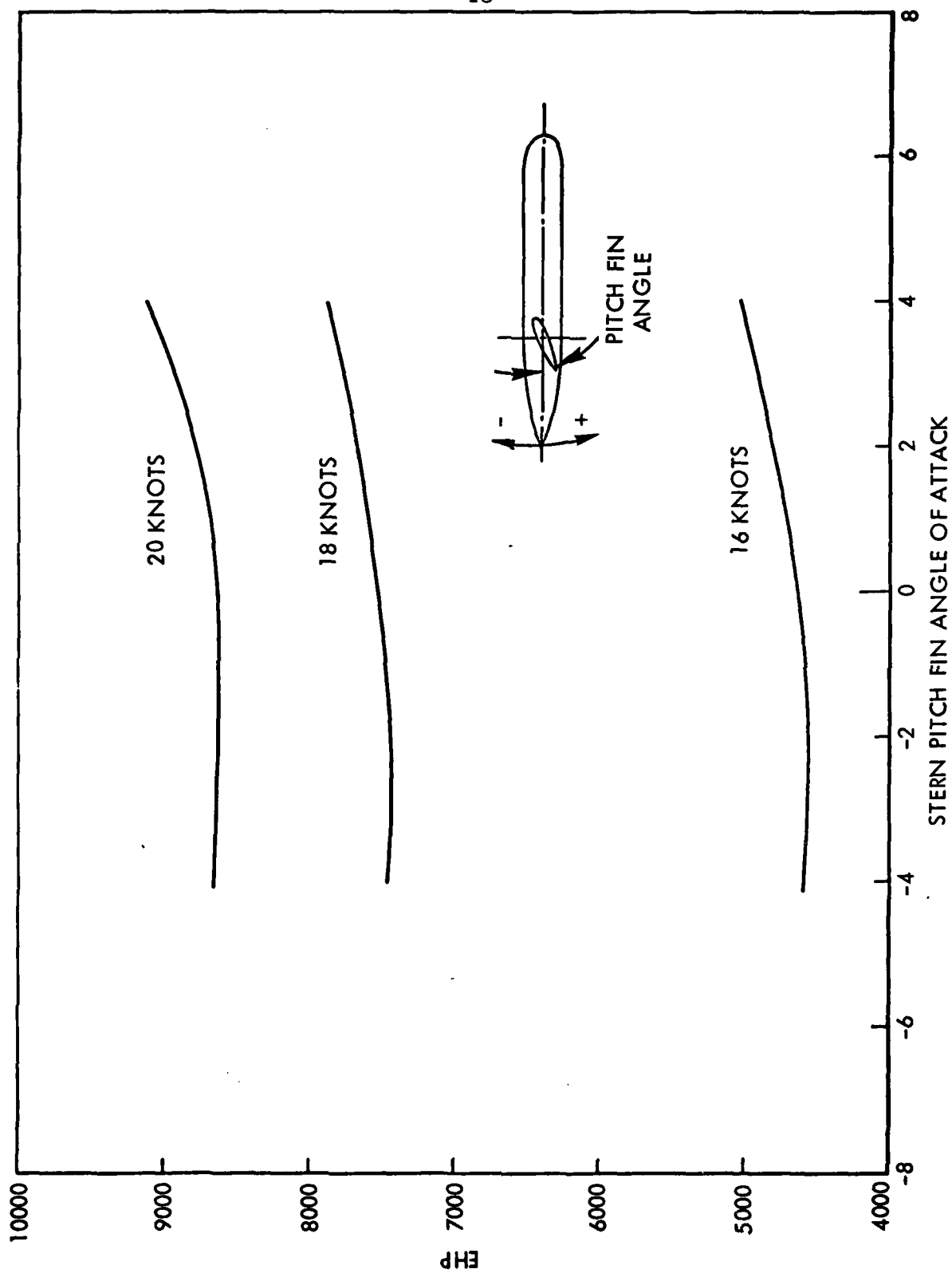


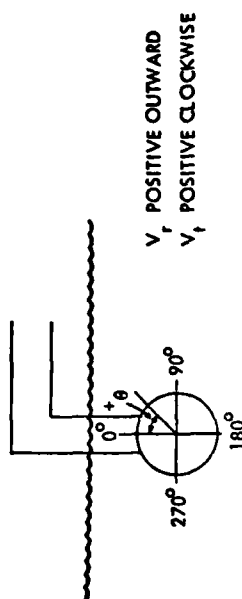
FIGURE 5 - VARIATION OF EHP WITH STERN PITCH FIN ANGLE OF ATTACK FOR FULLY APPENDED SWATH VII

Wake Characteristics

The data derived from the pitot-static yaw head rake measurements in the propeller plane have been reduced to components of longitudinal velocity V_x , radial velocity V_r and tangential velocity V_t . The individual data points, expressed in nondimensional form as ratios to model velocity, are listed in Table 7 for each of the four radial locations. The radial locations are nondimensionalized on lower hull diameter.

The data in Table 7 are plotted to show circumferential variation in Figures 6-9. Figure 6 gives circumferential distribution at $r/r_h = 0.375$, Figure 7 at $r/r_h = 0.675$, Figure 8 at $r/r_h = 0.975$ and Figure 9 for $r/r_h = 1.275$.

A contour map of the longitudinal velocity components is given in Figure 10.

TABLE 7 - TEST DATA FOR WAKE SURVEY TEST OF SWATH VII - RULLY
APPENDED AT 20 KNOTS

$\frac{r}{r_{hull}} = 0.375$				$\frac{r}{r_{hull}} = 0.675$				$\frac{r}{r_{hull}} = 0.975$				$\frac{r}{r_{hull}} = 1.275$			
THETA	V_x	V_r	V_T	THETA	V_x	V_r	V_T	THETA	V_x	V_r	V_T	THETA	V_x	V_r	V_T
0.0	0.7220	-0.1209	0.0641	0.0	0.8368	-0.0761	0.0735	0.0	0.8625	-0.0234	0.0749	0.0	0.8015	0.0163	0.0626
0.0	0.7171	-0.1210	0.0623	0.0	0.8318	-0.0760	0.0729	0.0	0.8558	-0.0272	0.0745	0.0	0.7937	0.0138	0.0600
15.0	0.6428	-0.0573	0.0214	15.0	0.8096	-0.0715	0.0724	15.0	0.8424	-0.0411	0.0847	15.0	0.9237	-0.0196	0.0649
15.0	0.6412	-0.0591	0.0184	15.0	0.8009	-0.0712	0.0712	15.0	0.8377	-0.0408	0.0822	15.0	0.9222	-0.0191	0.0655
30.0	0.5536	0.0279	0.0606	30.0	0.7523	-0.0562	0.0722	30.0	0.9518	-0.0371	0.0782	30.0	1.0084	0.0260	0.0562
30.0	0.5622	0.0230	0.0576	30.0	0.7380	-0.0532	0.0693	30.0	0.9460	-0.0587	0.0777	30.0	1.0031	-0.0218	0.0561
45.0	0.6388	-0.0026	0.1183	45.0	0.8046	-0.0259	0.0714	45.0	0.9707	-0.0196	0.0712	45.0	1.0027	-0.0210	0.0512
45.0	0.6184	-0.0051	0.1165	45.0	0.7758	-0.0211	0.0710	45.0	0.9633	-0.0387	0.0712	45.0	0.9587	-0.0215	0.0525
60.0	0.7854	-0.0837	0.1406	60.0	0.8381	-0.0283	0.0688	60.0	0.9647	-0.0417	0.0532	60.0	1.0179	-0.0100	0.0484
60.0	0.7731	-0.0844	0.1392	60.0	0.8235	-0.0297	0.0703	60.0	0.9568	-0.0412	0.0512	60.0	1.0021	-0.0239	0.0524
75.0	0.8440	-0.1224	0.1088	75.0	0.9357	-0.0357	0.0849	75.0	0.9975	-0.0600	0.0551	75.0	1.0016	-0.0351	0.0516
75.0	0.8316	-0.1200	0.1079	75.0	0.9248	-0.0341	0.0874	75.0	0.9963	-0.0577	0.0565	75.0	1.0026	-0.0315	0.0535
90.0	0.7854	-0.0837	0.0681	90.0	0.9107	-0.0319	0.0729	90.0	0.9971	-0.0459	0.0480	90.0	1.0179	-0.0349	0.0490
90.0	0.7755	-0.0791	0.0671	90.0	0.9179	-0.0316	0.0751	90.0	0.9933	-0.0451	0.0482	90.0	1.0083	-0.0218	0.0471
105.0	0.7033	-0.0138	0.0582	105.0	0.8974	-0.0216	0.0689	105.0	1.0029	-0.0447	0.0496	105.0	1.0131	-0.0354	0.0555
105.0	0.6919	-0.0184	0.0622	105.0	0.8860	-0.0207	0.0678	105.0	0.9987	-0.0459	0.0496	105.0	1.0089	-0.0372	0.0575
120.0	0.6817	-0.0423	0.0769	120.0	0.8907	-0.0541	0.0623	120.0	1.0018	-0.0442	0.0407	120.0	1.0015	-0.0387	0.0538
120.0	0.6817	-0.0413	0.0765	120.0	0.8856	-0.0542	0.0644	120.0	0.9970	-0.0440	0.0420	120.0	1.0053	-0.0384	0.0556
135.0	0.7012	-0.0589	0.0803	135.0	0.8500	-0.0737	0.0602	135.0	0.9991	-0.0446	0.0413	135.0	1.0119	-0.0326	0.0525
135.0	0.6919	-0.0594	0.0816	135.0	0.8410	-0.0758	0.0620	135.0	0.9961	-0.0452	0.0416	135.0	1.0017	-0.0341	0.0545
150.0	0.7060	-0.0615	0.0759	150.0	0.8974	-0.0566	0.0540	150.0	0.9990	-0.0459	0.0342	150.0	1.0115	-0.0502	0.0539
150.0	0.7033	-0.0607	0.0820	150.0	0.8879	-0.0561	0.0585	150.0	0.9928	-0.0463	0.0368	150.0	1.0063	-0.0501	0.0522
165.0	0.7110	-0.0538	0.0775	165.0	0.8984	-0.0774	0.0493	165.0	0.9952	-0.0466	0.0325	165.0	1.0114	-0.0320	0.0561
165.0	0.7072	-0.0611	0.0851	165.0	0.8937	-0.0775	0.0558	165.0	0.9897	-0.0464	0.0362	165.0	1.0047	-0.0317	0.0506
180.0	0.7144	-0.0653	0.0830	180.0	0.8974	-0.0580	0.0447	180.0	0.9972	-0.0480	0.0355	180.0	1.0129	-0.0322	0.0511
180.0	0.7050	-0.0645	0.0844	180.0	0.8935	-0.0575	0.0495	180.0	0.9932	-0.0480	0.0301	180.0	1.0040	-0.0319	0.0525
195.0	0.7127	-0.0638	0.0819	195.0	0.8969	-0.0593	0.0423	195.0	0.9973	-0.0483	0.0315	195.0	1.0102	-0.0347	0.0516
195.0	0.7138	-0.0655	0.0877	195.0	0.8906	-0.0594	0.0473	195.0	0.9918	-0.0490	0.0365	195.0	1.0051	-0.0355	0.0530
210.0	0.7137	-0.0674	0.0814	210.0	0.8957	-0.0611	0.0536	210.0	0.9958	-0.0489	0.0385	210.0	1.0102	-0.0320	0.0586
210.0	0.7163	-0.0697	0.0826	210.0	0.9005	-0.0618	0.0561	210.0	0.9944	-0.0492	0.0302	210.0	1.0049	-0.0376	0.0513
225.0	0.7120	-0.0638	0.0849	225.0	0.8946	-0.0589	0.0549	225.0	0.9926	-0.0500	0.0150	225.0	1.0031	-0.0341	0.0532
225.0	0.7120	-0.0638	0.0849	225.0	0.8946	-0.0589	0.0549	225.0	0.9926	-0.0500	0.0150	225.0	1.0031	-0.0341	0.0532
240.0	0.7105	-0.0632	0.0817	240.0	0.8955	-0.0595	0.0273	240.0	0.9966	-0.0488	0.0121	240.0	1.0115	-0.0313	0.0507
240.0	0.7127	-0.0701	0.0805	240.0	0.8955	-0.0604	0.0313	240.0	0.9955	-0.0494	0.0431	240.0	1.0074	-0.0327	0.0511
255.0	0.6973	-0.0634	0.0766	255.0	0.8935	-0.0585	0.0219	255.0	0.9929	-0.0478	0.0187	255.0	1.0034	-0.0304	0.0501
255.0	0.6973	-0.0634	0.0766	255.0	0.8935	-0.0585	0.0219	255.0	0.9929	-0.0478	0.0187	255.0	1.0034	-0.0304	0.0501
270.0	0.6729	-0.0635	0.0705	270.0	0.8910	-0.0541	0.0291	270.0	0.9951	-0.0465	0.0095	270.0	1.0116	-0.0330	0.0059
270.0	0.6770	-0.0652	0.0689	270.0	0.8932	-0.0553	0.0291	270.0	0.9927	-0.0471	0.0082	270.0	1.0113	-0.0300	0.0056
285.0	0.6191	-0.0432	0.0512	285.0	0.8769	-0.0508	0.0157	285.0	0.9918	-0.0456	0.0050	285.0	1.0035	-0.0245	0.0073
285.0	0.6221	-0.0502	0.0512	285.0	0.8769	-0.0508	0.0157	285.0	0.9918	-0.0456	0.0050	285.0	1.0035	-0.0245	0.0073
300.0	0.5915	-0.0156	0.0617	300.0	0.8917	-0.0500	0.0168	300.0	0.9894	-0.0460	0.0066	300.0	1.0009	-0.0274	0.0064
300.0	0.5938	-0.0404	0.0611	300.0	0.8917	-0.0500	0.0168	300.0	0.9894	-0.0460	0.0066	300.0	1.0009	-0.0274	0.0064
315.0	0.6312	-0.0604	0.0815	315.0	0.8324	-0.0566	0.0151	315.0	0.9845	-0.0443	0.0032	315.0	1.0032	-0.0218	0.0065
315.0	0.6348	-0.0631	0.0835	315.0	0.8324	-0.0566	0.0151	315.0	0.9845	-0.0443	0.0032	315.0	1.0032	-0.0218	0.0065
330.0	0.6725	-0.0631	0.0835	330.0	0.8127	-0.0577	0.0121	330.0	0.9713	-0.0453	0.0037	330.0	1.0031	-0.0205	0.0037
330.0	0.6725	-0.0631	0.0835	330.0	0.8127	-0.0577	0.0121	330.0	0.9713	-0.0453	0.0037	330.0	1.0031	-0.0205	0.0037
345.0	0.6819	-0.1043	0.0821	345.0	0.8282	-0.0729	0.0154	345.0	0.9514	-0.0489	0.0019	345.0	0.9878	-0.0247	0.0119
345.0	0.6812	-0.1105	0.0821	345.0	0.8282	-0.0729	0.0154	345.0	0.9514	-0.0489	0.0019	345.0	0.9878	-0.0247	0.0119
345.0	0.6970	-0.1116	0.0789	345.0	0.7420	-0.0651	0.0224	345.0	0.7693	-0.0326	0.0089	345.0	0.7553	-0.0212	0.0075

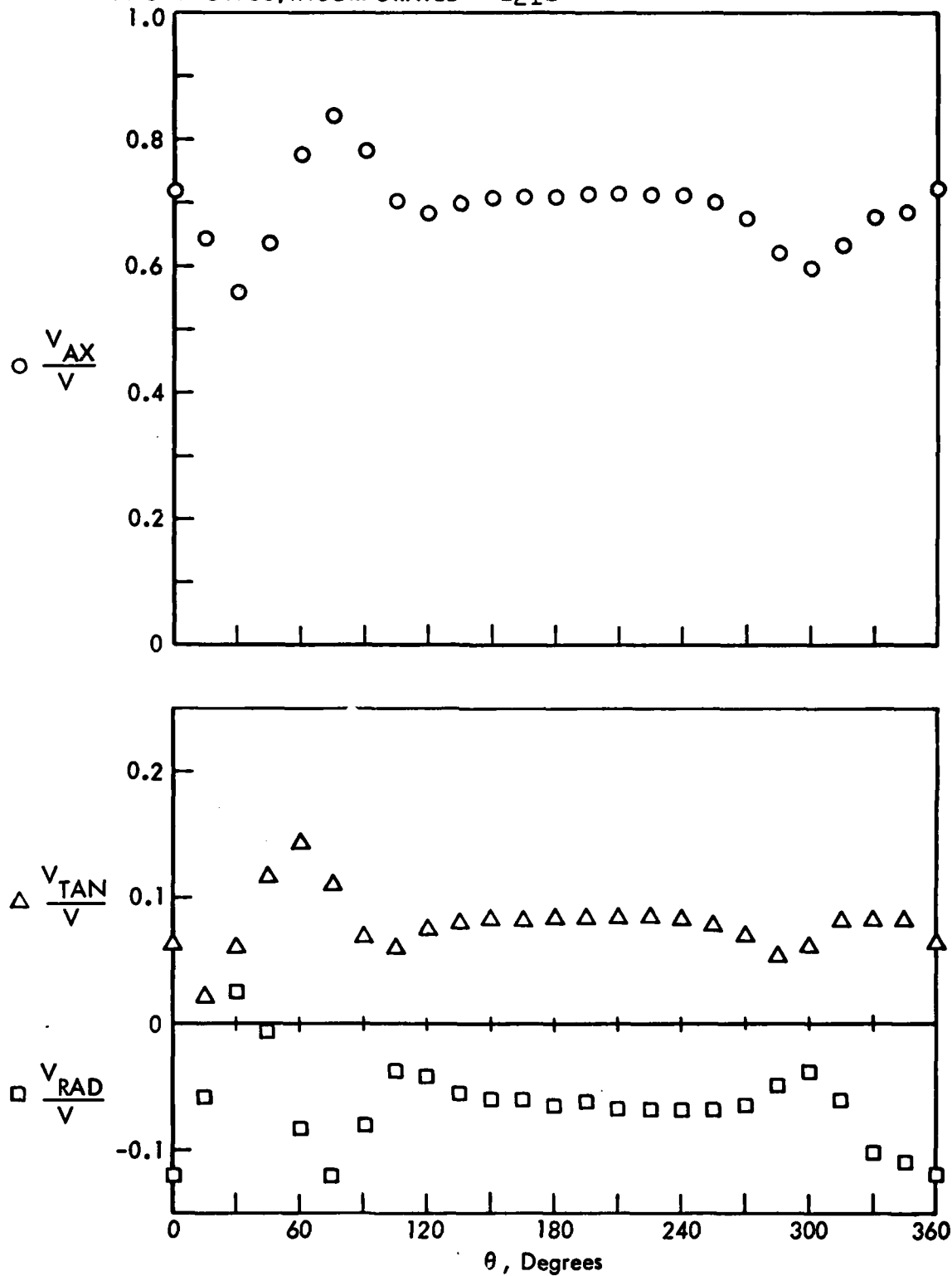


FIGURE 6 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR SWATH VII - APPENDED AT $r/r_h = 0.375$

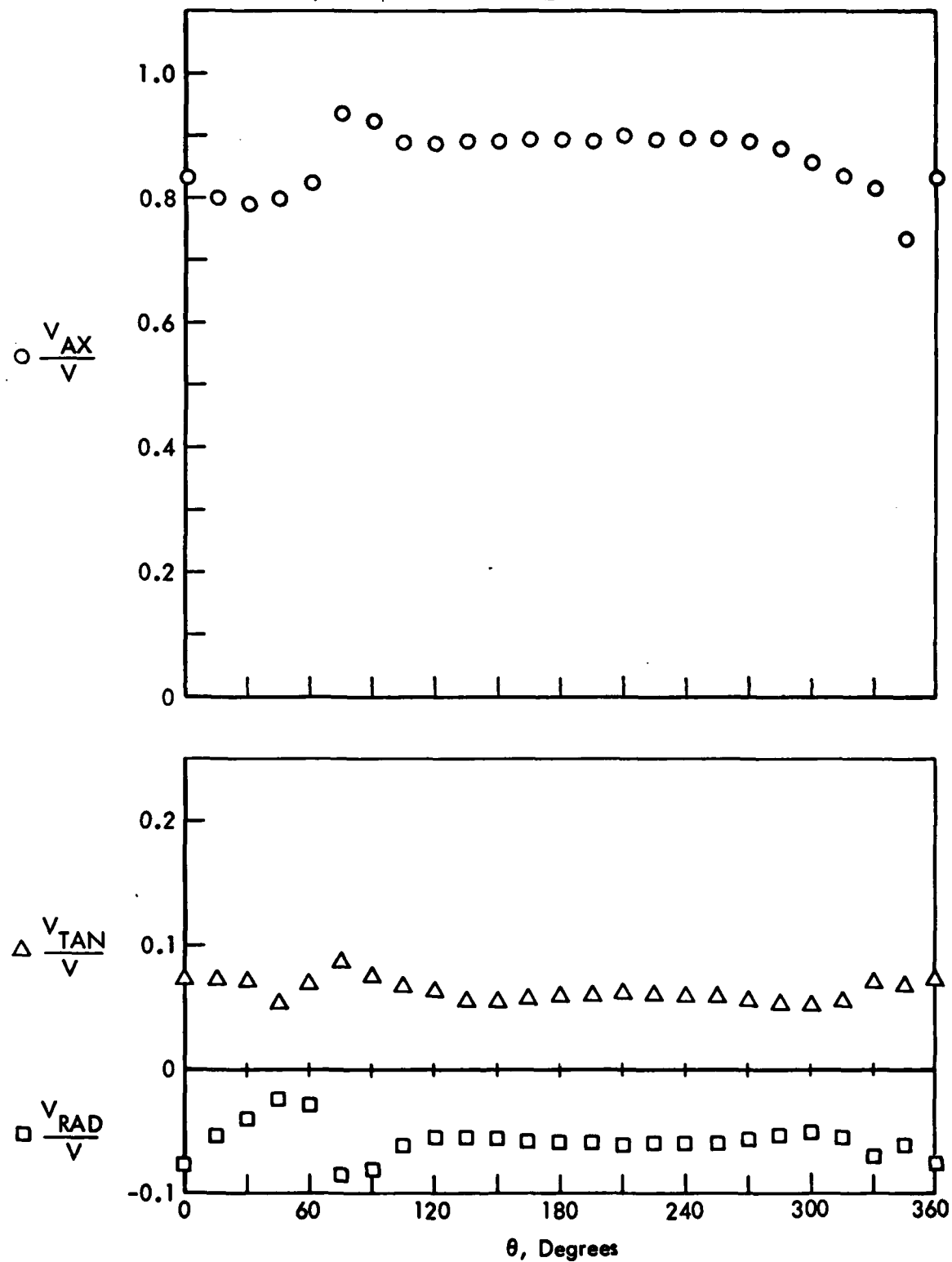


FIGURE 7 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR SWATH VII - APPENDED AT $r/r_h = 0.675$

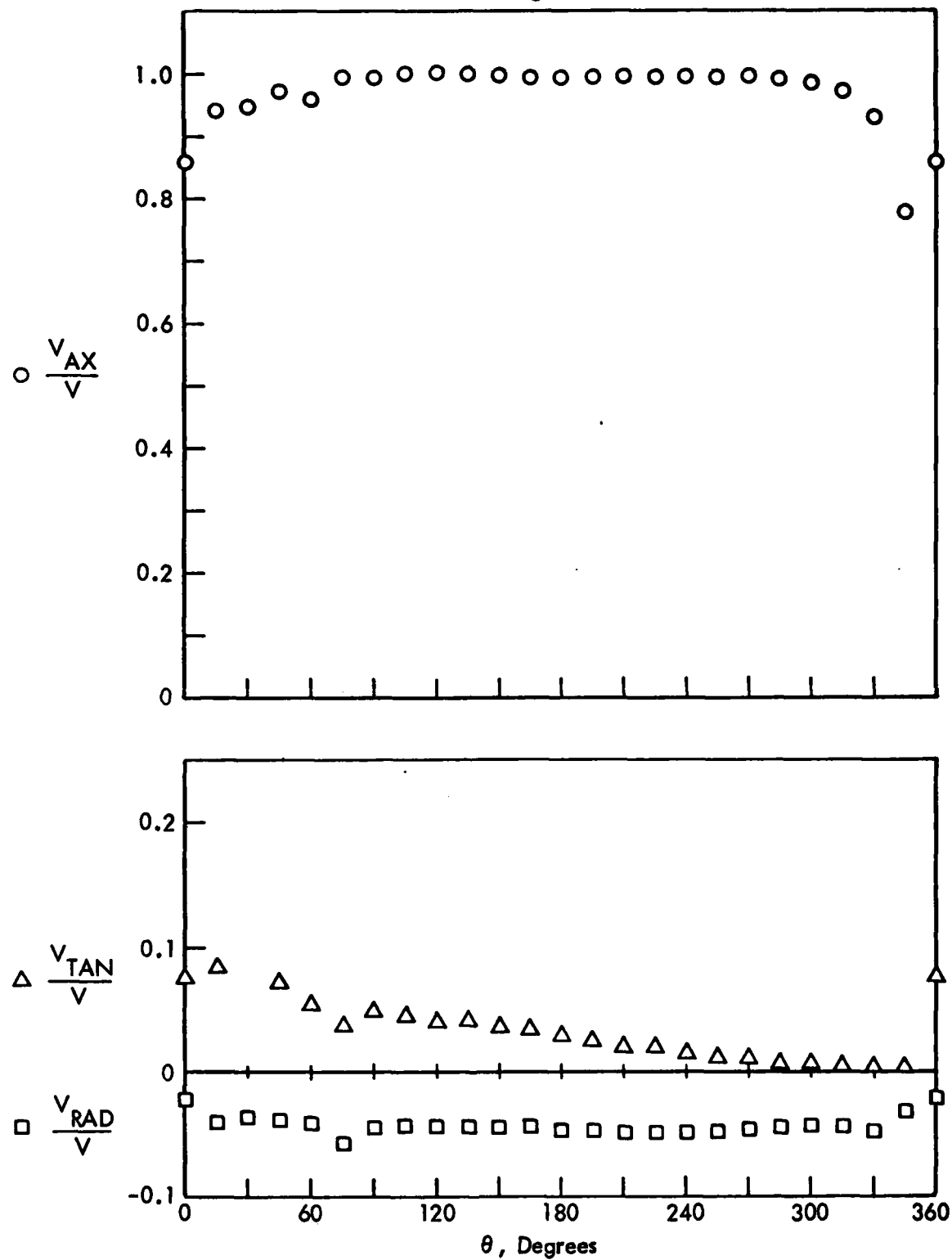


FIGURE 8 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR
SWATH VII - APPENDED AT $r/r_h = 0.975$

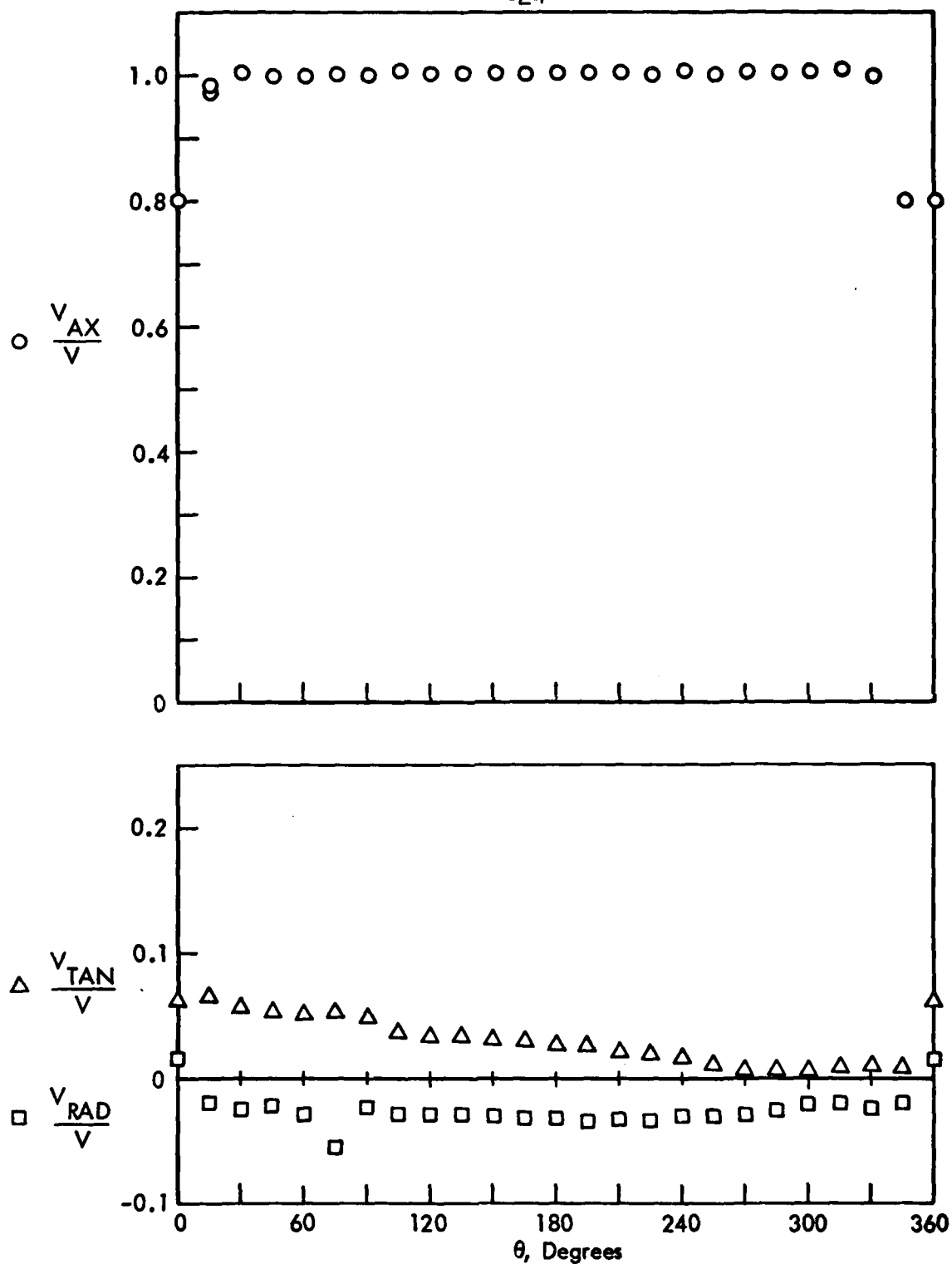


FIGURE 9 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR
SWATH VII - APPENDED AT $r/r_h = 1.275$

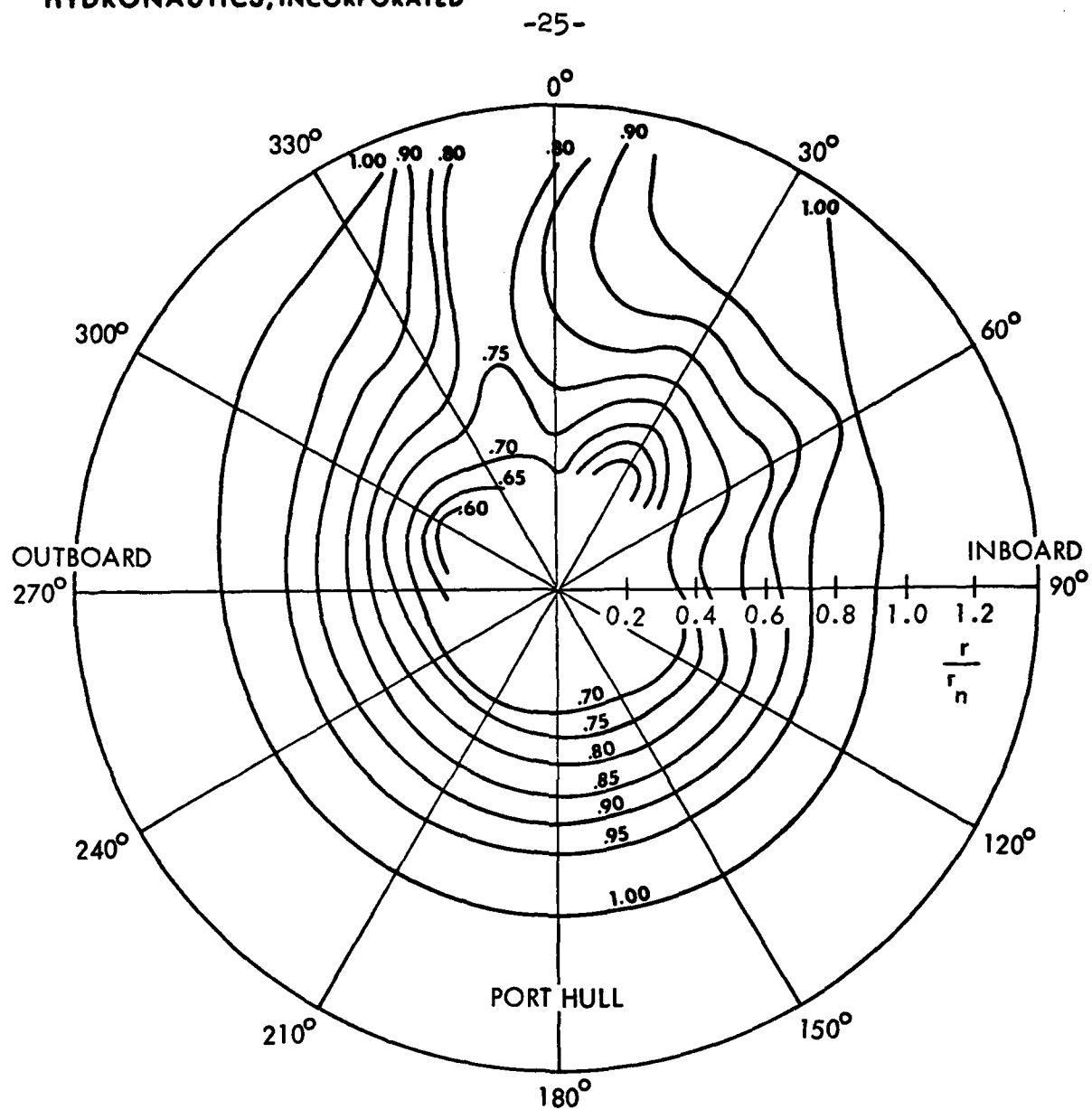


FIGURE 10 - CONTOUR MAP OF LONGITUDINAL VELOCITY COMPONENTS
IN THE PROPELLER PLANE FOR SWATH VII - APPENDED

ENGINEERING STUDIES

General

The experimental program described herein was devoted primarily to predictions of the SWATH resistance. However, speed power performance is also greatly affected by propulsor characteristics. Therefore, a number of engineering studies were carried out as described in the following sections to augment the resistance experiments for arriving at performance predictions.

Specific Propeller Designs

In accordance with Reference 1, propeller parametric designs were carried out for two particular propellers having diameter/hull diameter ratios of 0.90 and 1.10. These were tailored to the EHP and wake characteristics of SWATH VII at 20 knots. For each propeller, the BAR was selected based upon cavitation considerations, and an arbitrary thickness distribution was selected so as to give conservative stress levels. Using these, and a variety of pitch distributions, calculations of the propulsive coefficient were made for a range of shaft rpm values. The results are shown in Figure 11 for Propeller 7694-90 and in Figure 12 for Propeller 7694-110. The assumed hull/propeller interaction factors are also shown. Open water efficiencies are not shown because these are wake adapted propellers. Details of the calculations and the propeller configurations are given in Appendix C. From this range of designs, the maximum propulsive efficiency was designated as the optimum. The characteristics of these two propellers are given in Table 8. Of course,

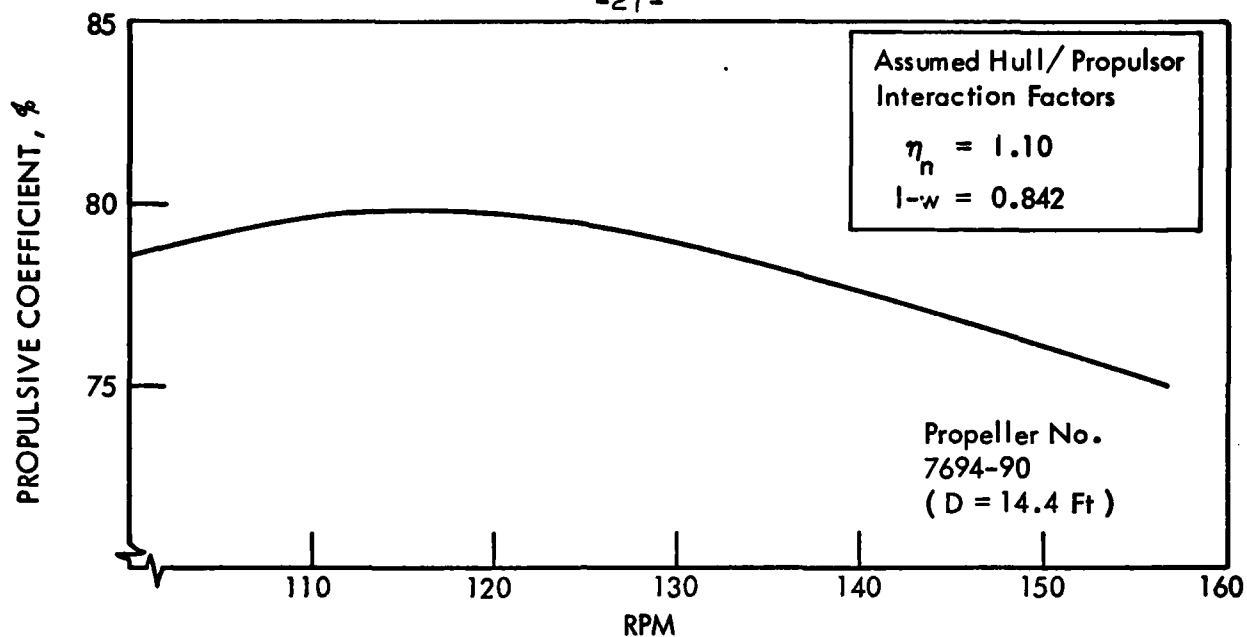


FIGURE 11 - VARIATION OF PROPULSIVE COEFFICIENT WITH RPM FOR PROPELLER 7694-90

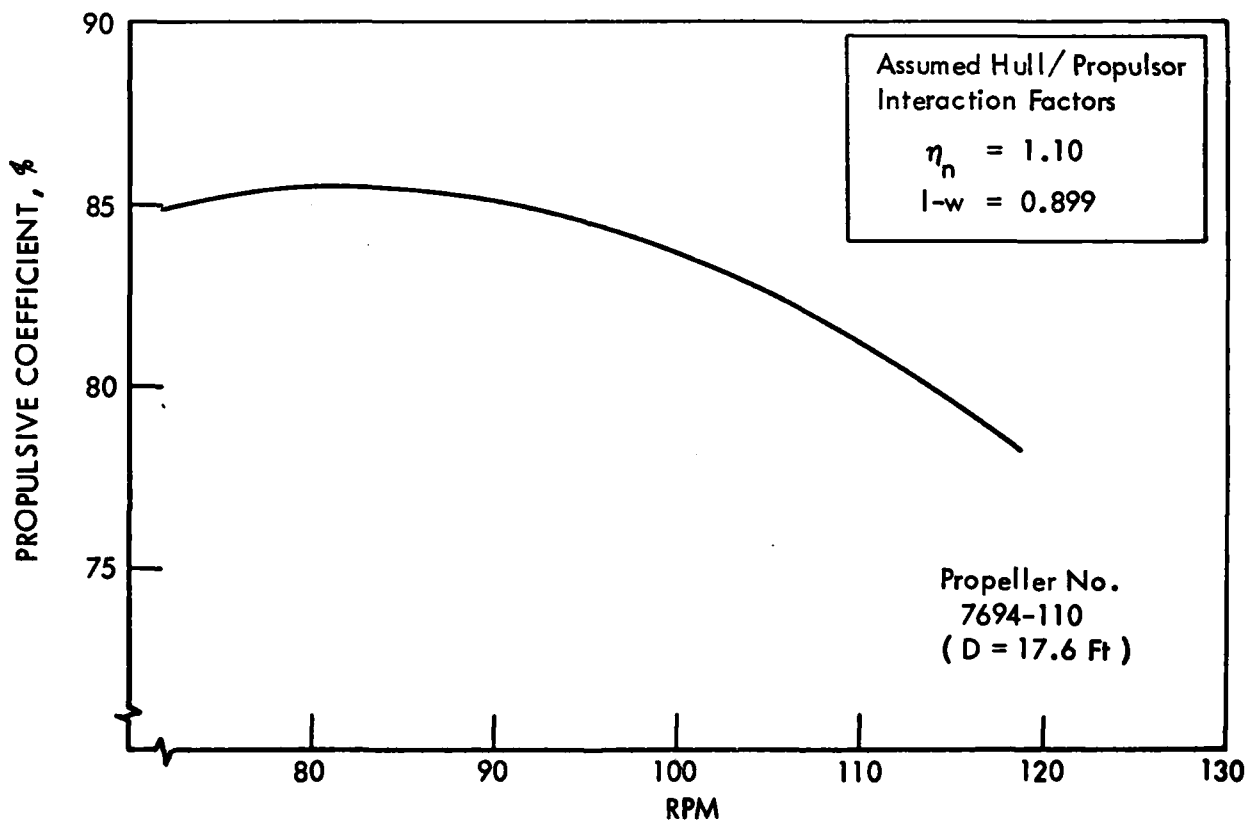


FIGURE 12 - VARIATION OF PROPULSIVE COEFFICIENT WITH RPM FOR PROPELLER 7694-110

Table 8
Characteristics of Specific Propeller
Designs Wake Adapted to
SWATH VII

Characteristic	7694-90	7694-110	7694-110-36
Diameter/Hull Diameter Ratio	0.90	1.10	1.10
Diameter, Feet	14.4	17.6	17.6
BAR	0.55	0.50	0.78
Optimum RPM	117	82	130

other considerations will ultimately enter into the propeller design optimization.

Effects of Diameter Variation

In addition to the two specific propeller designs previously described, a family of other props were investigated in less detail to gain insight into the efficiency variation with changes in diameter at optimum rpm values. The estimated propulsive efficiencies and rpm values for this family are shown in Figure 13.

Off-Design Propeller Performance

Subsequent to the diameter and RPM variation studies described above, two propellers having diameter/hull diameter ratios of 1.1 were investigated at off-design. One of these was the 20-knot design propeller designated 7694-110, and a new design was performed designated 7694-110-36 for operation at 36-knots. The characteristics of this propeller are also given in Table 8. The operating RPM of this second propeller was chosen as 130 with a drag of 28,575 kgs. A lower RPM (higher J) would have more favorable cavitation characteristics, but an impractically high pitch-diameter ratio. The off-design performance of these two propellers is given in Figures 14 and 15 and in Table 9. Supplemental design data for propeller 7694-110-36 is given in Appendix C.

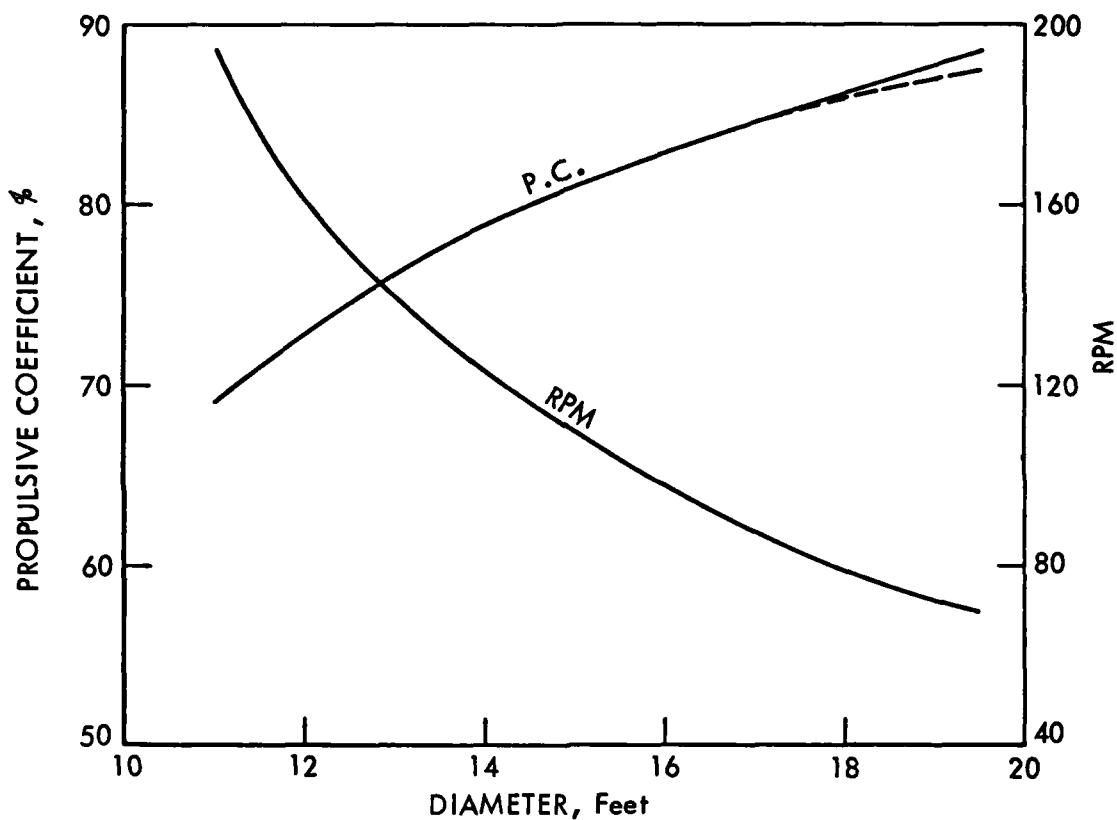


FIGURE 13 - VARIATION OF OPTIMUM P.C. AND RPM WITH DIAMETER FOR SWATH VII SHIP AT 20 KNOTS

NOTE: The solid line represents the calculated values of P.C. for a constant value (1.10) of η_H for all diameters - giving $(1-t) > 1$ for large diameters. In reality, $(1-t)$ should level off at 1 for large diameters giving P.C. as indicated by broken line. (Self-propulsion tests with large propellers would give correct estimates of thrust-deduction in those cases.)

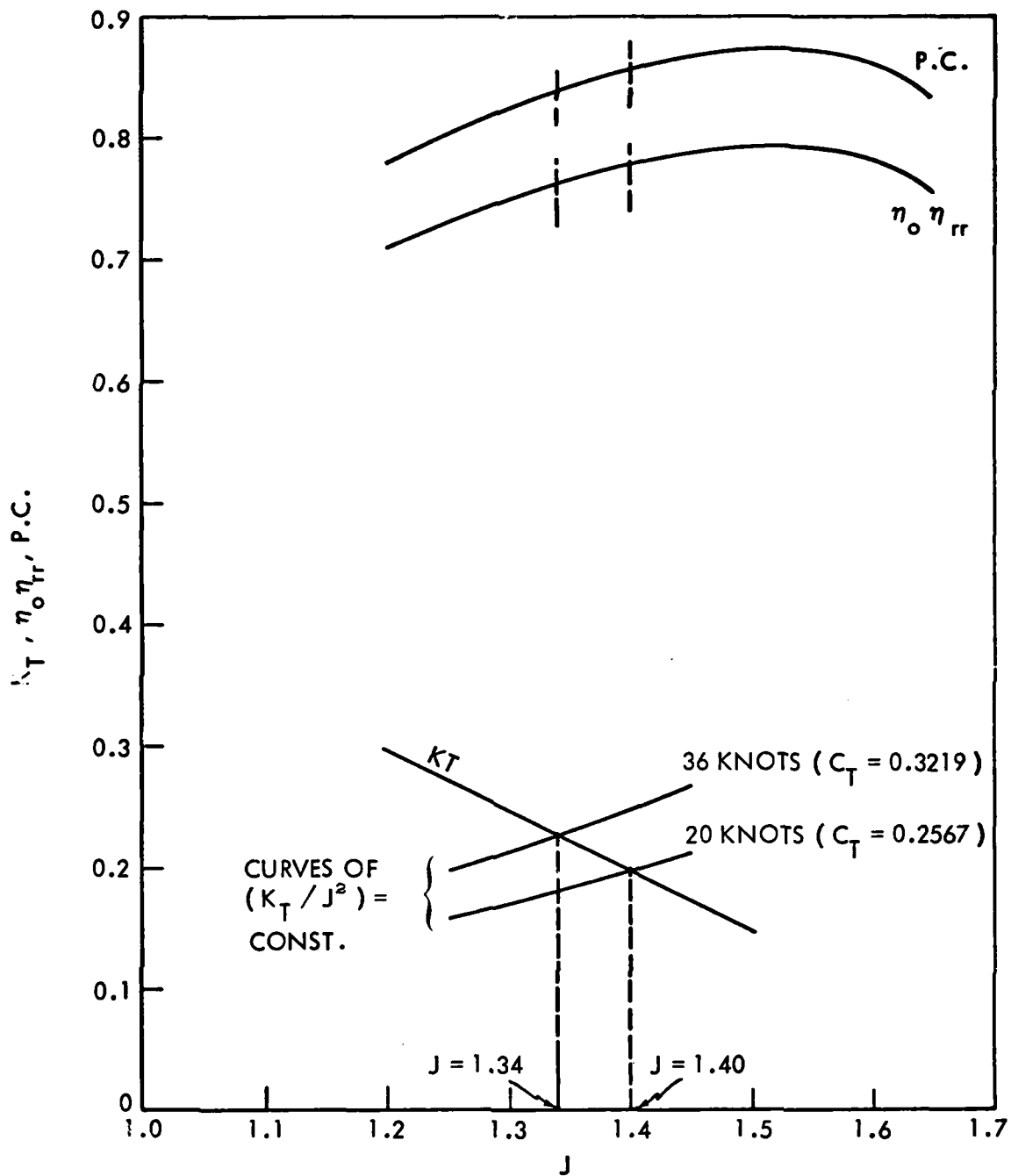


FIGURE 14 - PREDICTED PERFORMANCE OF PROPELLER 7694-110 FOR SWATH VII

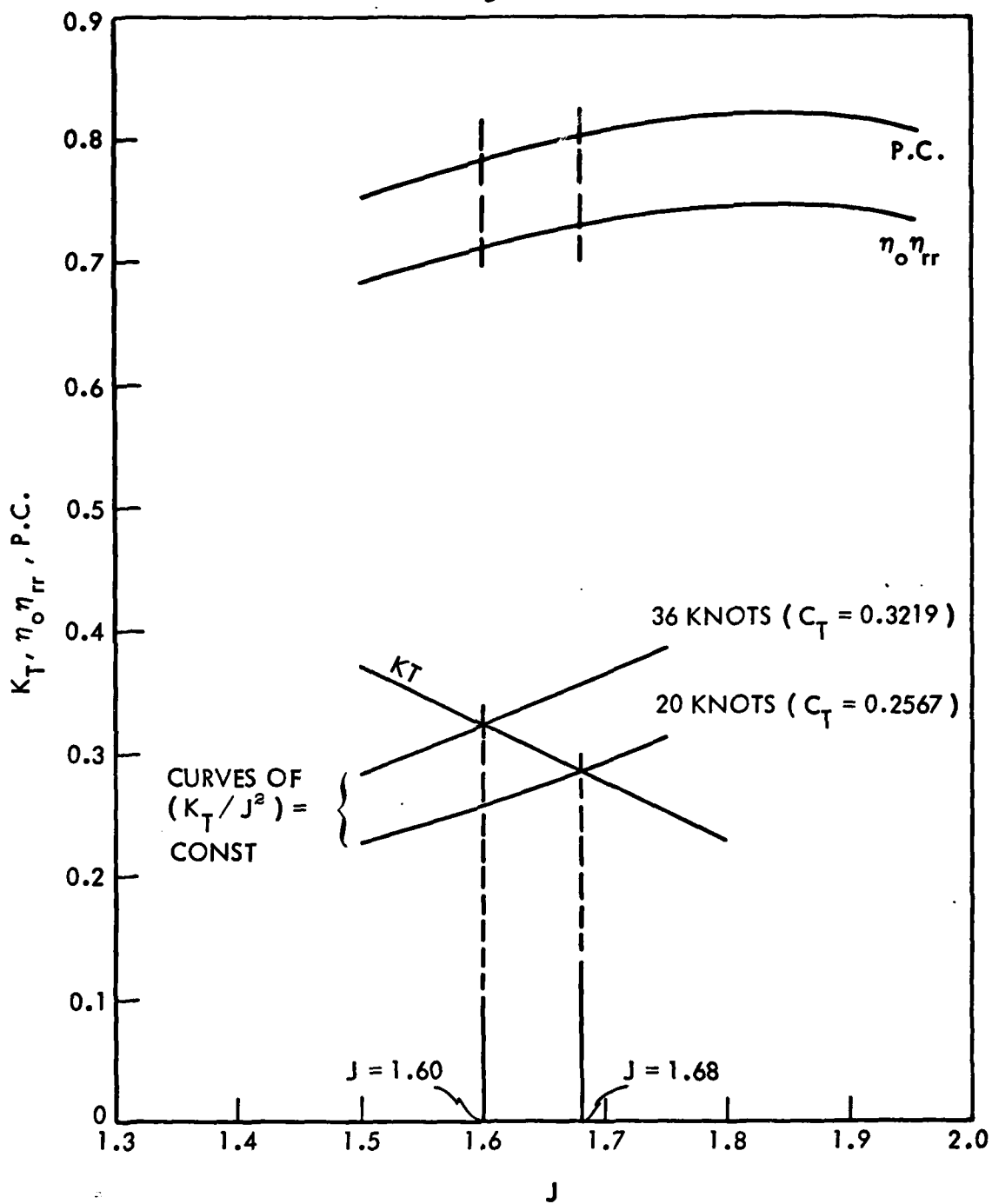


FIGURE 15 - PREDICTED PERFORMANCE OF PROPELLER 7694-110-36 FOR SWATH VII

TABLE 9
Performance of Propellers 7694-110
and 110-36 at Off-Design Speeds

Prop. No.	Design Speed	Off-Design Speed (knots)	RPM	P.C.	Cav. Margin at .7R	Gawn-Burrill Coeffs. at .7R ¹	Extent of Cavitation
7694-110	20	36	155	0.837 ²	0.818	$\tau = .256$ $\sigma = .261$	50% or more of blade surface
7694-110-36	36	20	69	0.803	5.427	$\tau = .204$ $\sigma = 1.173$	Virtually none

¹Gawn-Burrill coefficients are calculated using the mean wake of 0.1006.

²This P.C. value has no meaning because of thrust breakdown not accounted for in the calculations.

Extraordinary Machinery Operating Conditions

The study for locked and free-wheeling shaft, as well as the calculation of power required to keep one propeller at zero thrust were carried out using four-quadrant data published in Reference 3.

In the cases of locked and free-wheeling shaft, the optimum pitch is the highest obtainable. For the purpose of calculations, this was assumed to be 120 percent of design pitch. The four-quadrant thrust and torque coefficients are defined as:

$$C_T' = T/\frac{1}{2}\rho[V_A^2 + (.7\pi nD)^2]A ,$$

and

$$C_Q' = Q/\frac{1}{2}\rho[V_A^2 + (.7\pi nD)^2]AD ,$$

where

T: thrust

Q: torque

ρ : density of water

V_A : velocity of advance

n: rps

D: propeller diameter

A: propeller disk area

Inflow angle, $\beta = \arctan (V_A/.7\pi nD)$

The locked-shaft drags were calculated using C_T' as given in the four-quadrant data, for the appropriate pitch-ratios, and zero rotational speed (i.e., for $\beta = 90^\circ$). (C_T' is negative at $\beta = 90^\circ$ and, therefore, it gives negative thrust - i.e., drag.) The results of these calculations are given in Table 10.

In the case of free-wheeling propeller, the assumed torque was 1 percent of full power torque.

For a range of β , values of C_Q' were plotted on the four-quadrant data chart using this value of Q ; the value of β corresponding to the appropriate pitch-diameter ratio was picked and the corresponding rotational speed was calculated.

The value of C_T' corresponding to this combination of pitch and β was obtained from four-quadrant data chart, and the drag was calculated using this C_T' . The results of these calculations are given in Table 11.

In order to calculate the power required to keep one shaft at zero thrust, values of β and C_Q' were picked from four-quadrant data chart at $C_T' = 0$. The rotational speed corresponding to this value of β was calculated. The torque, Q , was then calculated to give the power. The results of these calculations are given in Table 12.

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TABLE 10
SWATH VII Performance,
One Locked Shaft at 20 Knots

Prop. No.	Drag (Kgs)
7694-110	39009
7694-110-36	50670

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TABLE 11
SWATH VII Performance,
One Free-Wheeling Shaft at 20 Knots

Prop. No.	Assumed Torque	Drag (Kgs)
7694-110	1% of torque on one shaft at 20 knots	9525
7694-110-36	1% of torque on one shaft at 20 knots	10140
7694-110-36	1% of torque on one shaft at 36 knots	17790

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TABLE 12

SWATH VII Performance,
Power Required to Keep One Shaft
at Zero Thrust at 20 Knots

Prop. No.	Required Power (SHP)
7694-110	770 (15% of one shaft power at 20 knots)
7694-110-36	960 (18% of one shaft power at 20 knots)

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-39-

REFERENCES

1. Contract N00600-76-C-1393
2. Gertler, Kohl and Kirkman, "Experimental Investigation of a Systematic Series of Low Length-Beam Ratio, High Block Co-efficient Merchant Ship Forms," HYDRONAUTICS, Incorporated Technical Report 7166-1, June 1973.
3. "Prediction of Controllable-Pitch Propeller Performance in Off-Design Conditions," J. Strom-Tejsen and R. R. Porter, Paper VII B-1, Third Ship Control Systems Symposium, Ministry of Defence, Foxhill, Berth, Somerset, U.K.

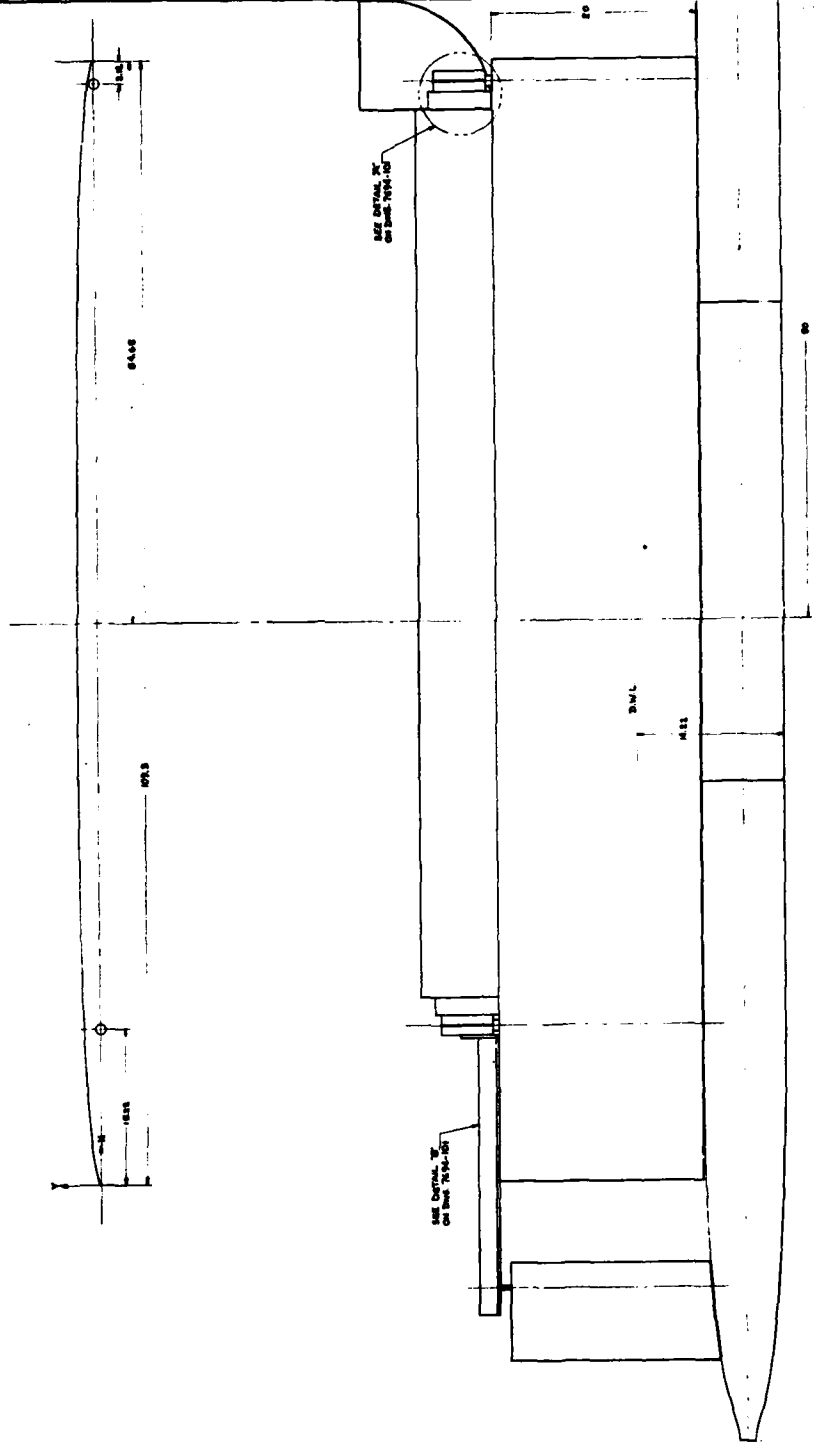
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APPENDIX A
MODEL DRAWINGS

7694-100
PAGE 100

POLAROID, INK-JET OR OTHER METHOD
 NAME AND TITLE (PRINT)
 DATE ☒ 10/1/00 ☐ 10/2/00 ☐ 10/3/00
 SIGNATURE ☐ 10/1/00 ☐ 10/2/00 ☐ 10/3/00

1. REF PAGE
A. HSPC C-26(4-1)
B. Memo from TSC-107



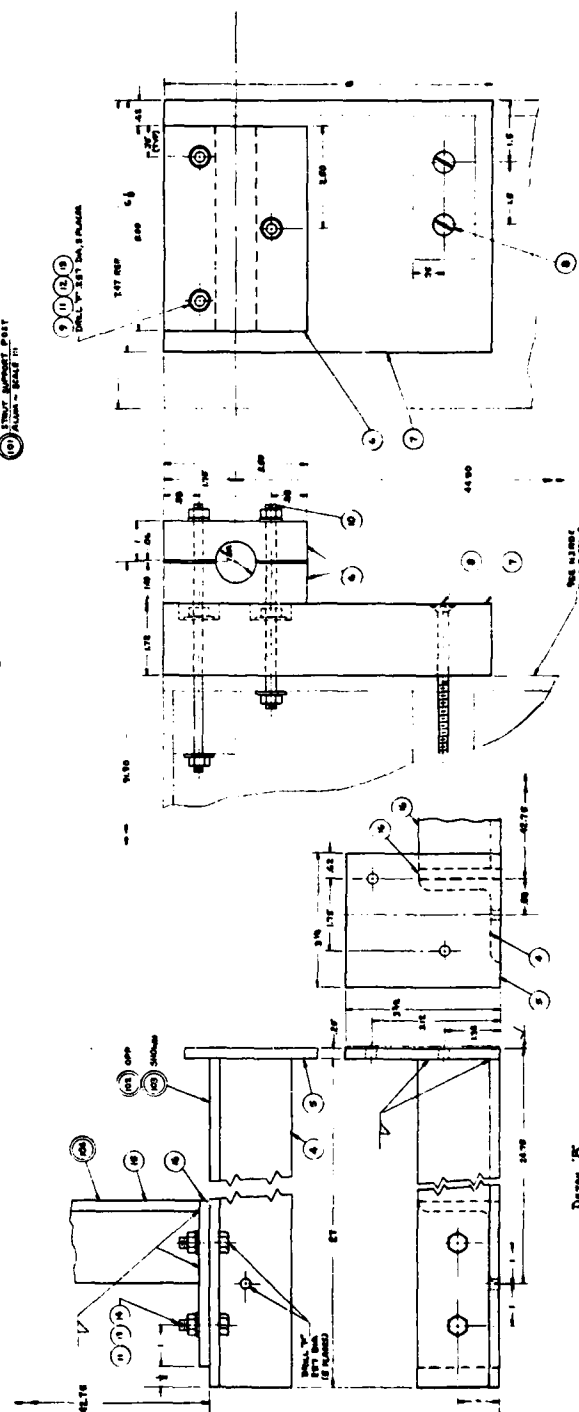
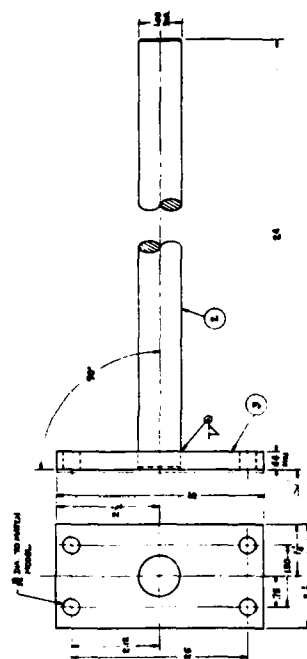
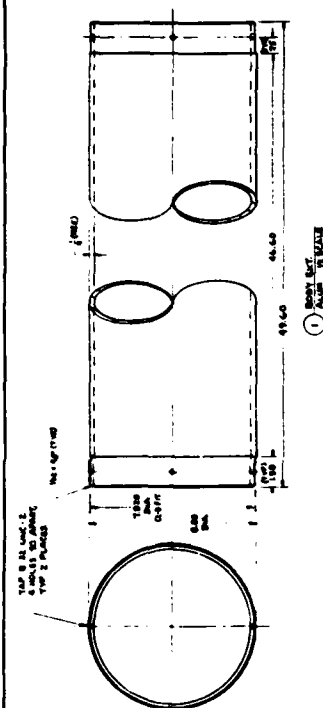
7694-100

HYDRONAUTICS, INCORPORATED
P.O. BOX 10000, CHICAGO, ILL. 60680

2700 TON SWATH MODEL
GENERAL ARRANGEMENT

[illegible]

7694-101

[illegible]

HYDRONAUTICS, INCORPORATED

4225 SCALE
2700 TON SWATH MODEL
DETAILS

[illegible]

HYDRONAUTICS, Incorporated

APPENDIX B

MODEL RESIDUARY RESISTANCE COEFFICIENTS

- B-1 - Residuary Resistance Coefficient Test Data for SWATH VI-A -
Fully Appended (Model 7694-1)
- B-2 - Residuary Resistance Coefficient Test Data for SWATH VII -
Bare Hull (Model 7694-2)
- B-2 - Residuary Resistance Coefficient Test Data for SWATH VII -
Fully Appended (Model 7694-2)

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B-1

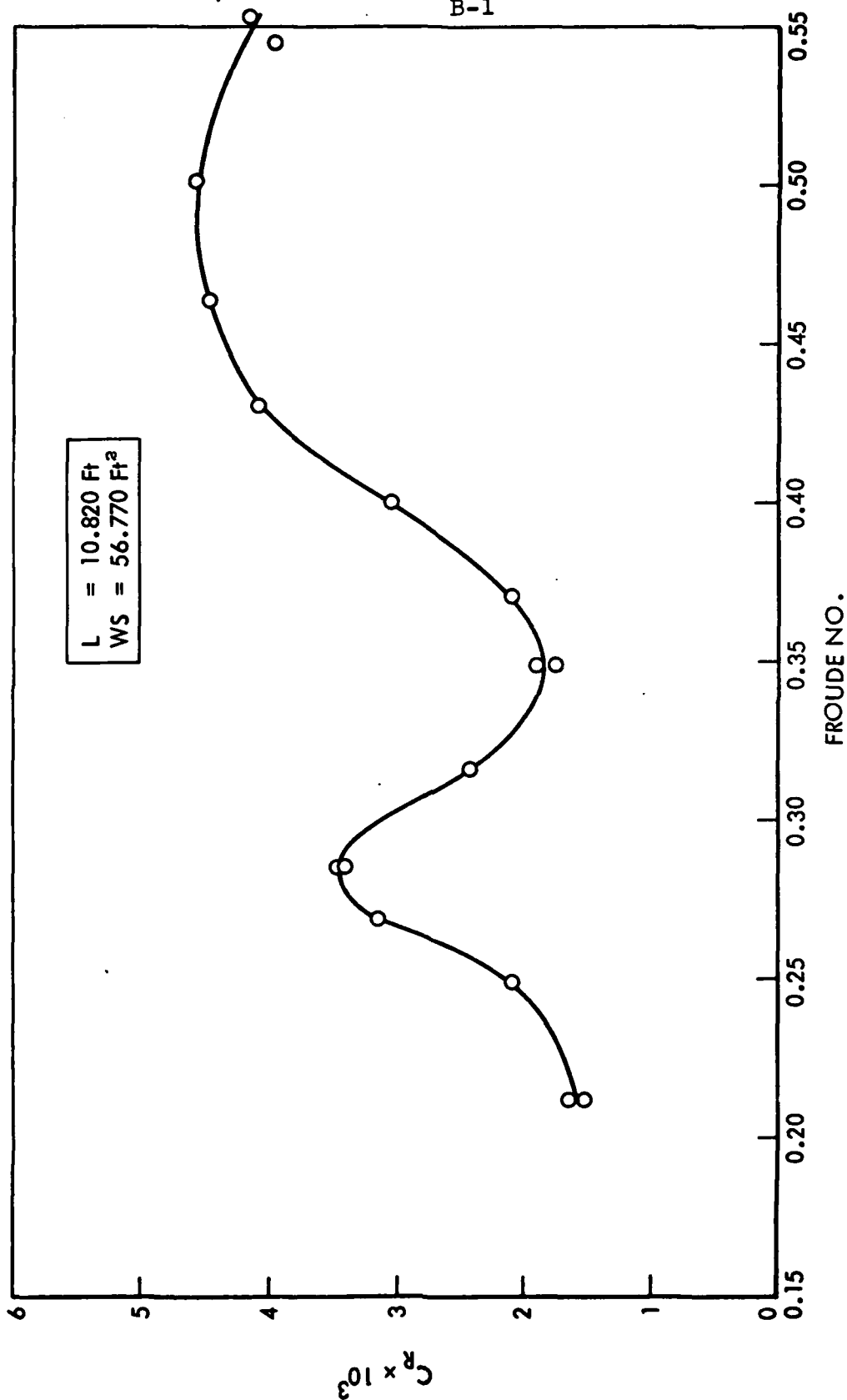


FIGURE B-1 - RESIDUARY RESISTANCE COEFFICIENT TEST DATA FOR SWATH VI-A -
FULLY APPENDED (MODEL 7694-1)

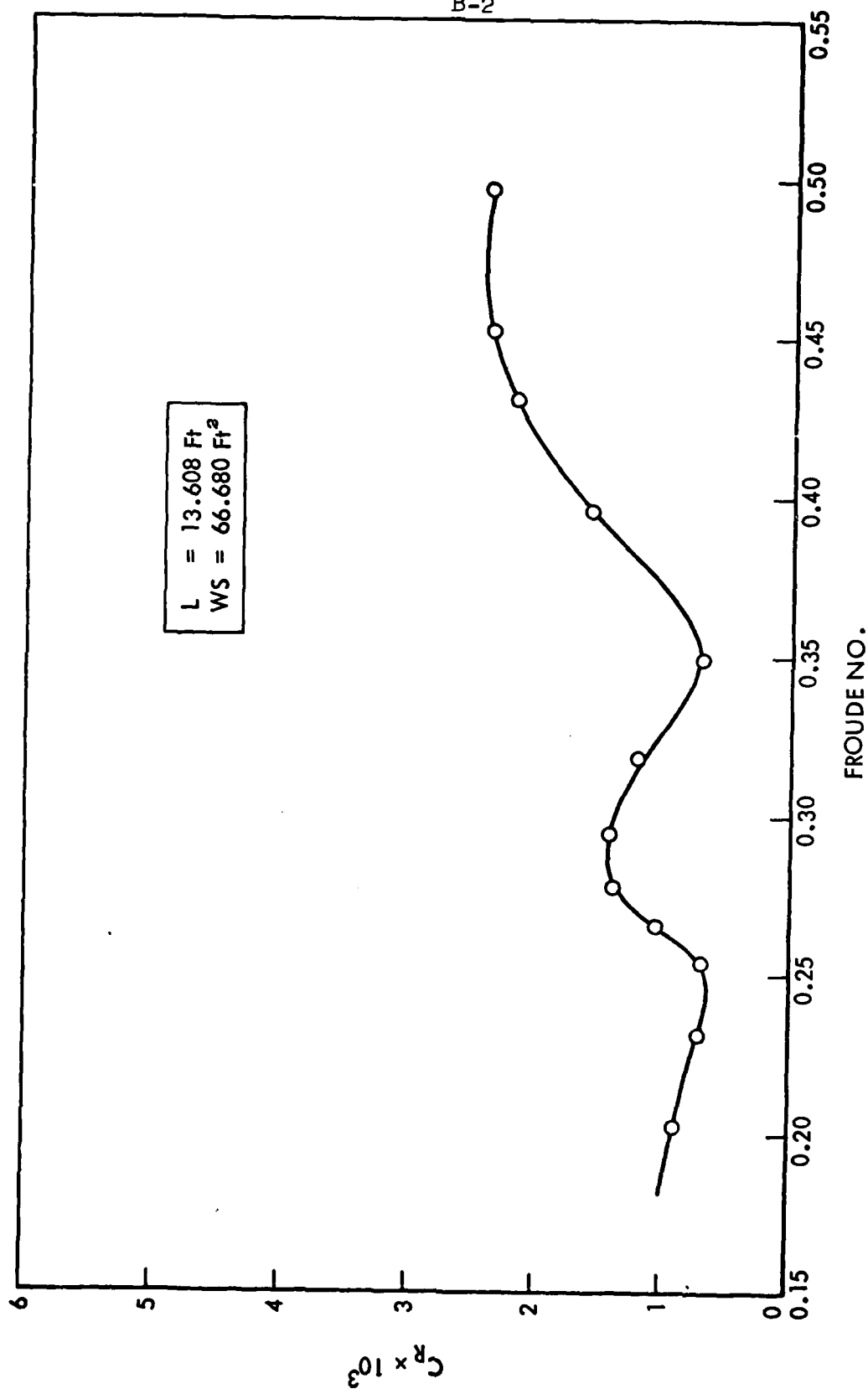


FIGURE B-2 - RESIDUARY RESISTANCE COEFFICIENT TEST DATA FOR SWATH VII -
BARE HULL (MODEL 7694-2)

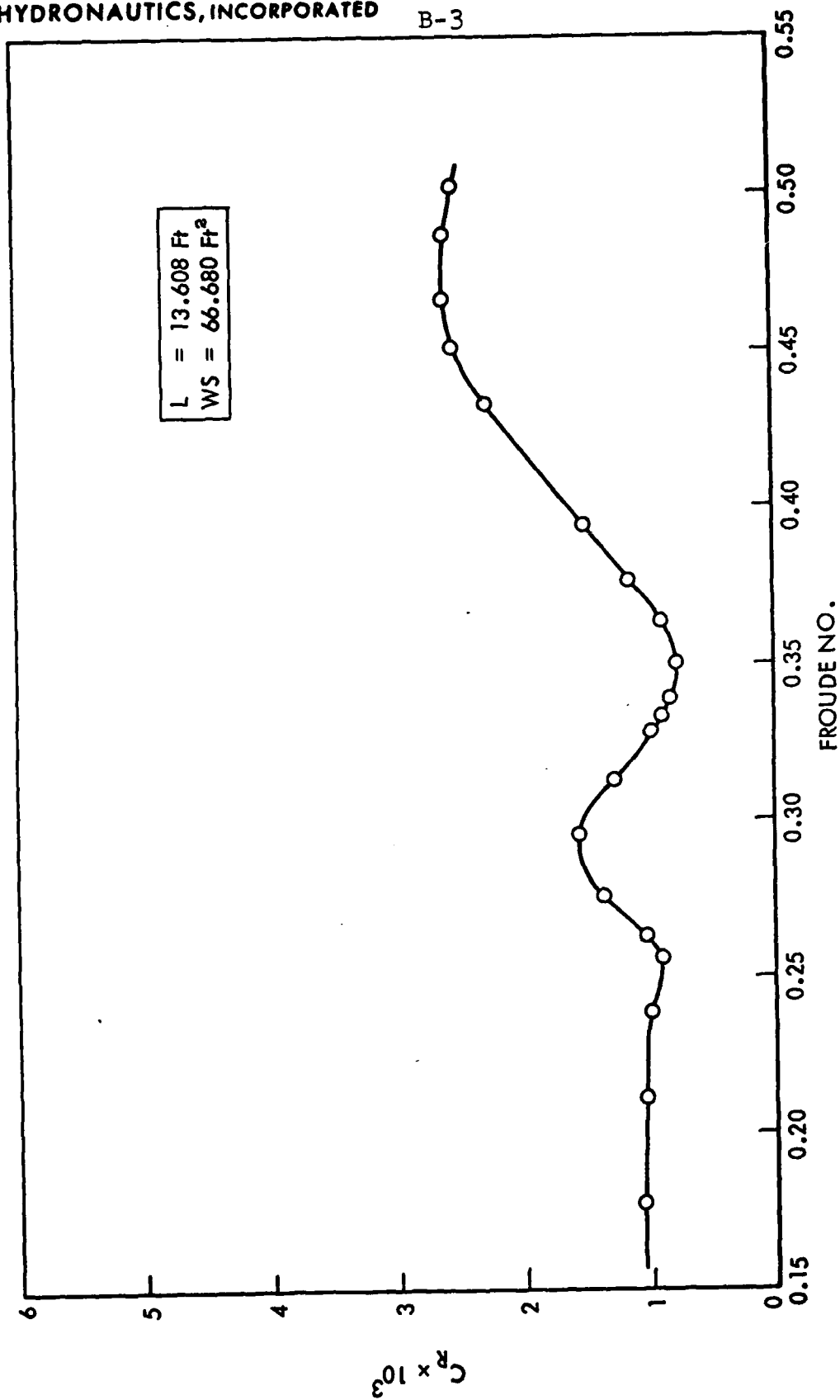


FIGURE B-3 - RESIDUARY RESISTANCE COEFFICIENT TEST DATA FOR SWATH VII - FULLY APPENDED (MODEL 7694-2)

HYDRONAUTICS, Incorporated

APPENDIX C
DETAILS OF PROPELLER DESIGNS

-C1-

1.2000 J	CT = 0.4095	CTI = 0.4221	MAX	CHORD AT 0.640R	0.0370 T/D AT 0.300R
LAMBDA	CP = 0.4754	CPI = 0.4773	ROOT	CHORD IS 0.550	0.0230 T/D AT 0.600R
0.3019	KT = 0.2315	KTI = 0.2387	OF	MAX CHORD	0.0100 T/D AT 0.900R
0.3000 HUB RADIUS	KO = 0.0513	KOI = 0.0483	SIG-T = 2.3800 * T/C		0.0400 T/C MIN
5.0000 BLADES	ETA = 0.8613	ETAI = 0.9437	SIG-L = 0.5560 * CL		0.0100 CD AT ROOT
0.5500 EAR					0.0080 CD AT TIP
					2.9600 ADVANCE SIGMA
					0.4095 CT REQUIRED
					1.0308 CTI/CT
0.2999	0.3468	0.4749	0.6499	0.8249	0.9531
0.0000	0.5000	0.8600	0.9800	0.7900	0.4000
0.0000	0.4923	0.8678	0.9796	0.7828	0.4073
0.3880	0.3570	0.2700	0.1730	0.1000	0.0580
0.0280	0.0220	0.0200	0.0120	0.0110	0.0100
0.3000	0.1645	0.37000	0.1260	0.0908	0.9454
0.350	0.2063	3.4465	0.1329	0.1145	1.0749
0.400	0.2377	3.2018	0.1347	0.1344	1.2064
0.450	0.2614	2.5655	0.1358	0.1503	1.3389
0.500	0.2789	2.7370	0.1330	0.1623	1.4716
0.550	0.2908	2.5155	0.0865	0.1705	1.6042
0.600	0.2974	2.3000	0.0773	0.1751	1.7364
0.650	0.2990	2.0893	0.0699	0.1761	1.8681
0.700	0.2952	1.8816	0.0637	0.1738	1.9992
0.750	0.2858	1.6744	0.0586	0.1684	2.1297
0.800	0.2699	1.4638	0.0542	0.1602	2.2597
0.850	0.2459	1.2433	0.0506	0.1493	2.3892
0.900	0.2108	1.0000	0.0471	0.1363	2.5183
0.925	0.1869	0.8615	0.0464	0.1291	2.5827
0.950	0.1563	0.7011	0.0448	0.1214	2.6470
0.975	0.1134	0.4957	0.0437	0.1135	2.7113
0.990	0.0729	0.3143	0.0431	0.1085	2.7499
1.000	0.0000	0.0000	0.0400	0.1051	2.7756
0.300	0.0012	1.0445	0.3325	1.1083	38.789
0.350	1.3021	1.1009	0.3504	1.0013	35.918
0.400	1.7870	1.1505	0.3662	0.9156	33.585
0.450	2.1071	1.1934	0.3799	0.8442	31.636
0.500	2.3227	1.2296	0.3914	0.7828	29.971
0.550	2.4559	1.2594	0.4009	0.7288	28.521
0.600	2.5174	1.2828	0.4083	0.6806	27.236
0.650	2.5331	1.3004	0.4139	0.6368	26.081
0.700	2.4462	1.3124	0.4177	0.5968	25.031
0.750	2.3180	1.3192	0.4199	0.5598	24.065
0.800	2.1277	1.3214	0.4206	0.5258	23.168
0.850	1.8710	1.3196	0.4200	0.4941	22.328
0.900	1.5553	1.3143	0.4183	0.4648	21.536
0.925	1.3278	1.3106	0.4172	0.4510	21.156
0.950	1.0798	1.3063	0.4158	0.4377	20.784
0.975	0.7585	1.3015	0.4143	0.4249	20.421
0.990	0.4771	1.2984	0.4133	0.4175	20.208
0.0010	1.2963	0.4126	0.4126	0.4126	20.066
0.300	0.0012	1.0445	0.3325	1.1083	38.789
0.350	1.3021	1.1009	0.3504	1.0013	35.918
0.400	1.7870	1.1505	0.3662	0.9156	33.585
0.450	2.1071	1.1934	0.3799	0.8442	31.636
0.500	2.3227	1.2296	0.3914	0.7828	29.971
0.550	2.4559	1.2594	0.4009	0.7288	28.521
0.600	2.5174	1.2828	0.4083	0.6806	27.236
0.650	2.5331	1.3004	0.4139	0.6368	26.081

SAWN-BURRILL COEFFICIENTS AT 0.700 RADIUS $\tau(u) = 0.2045$ $\sigma(u) = 0.6233$

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GAWN-BURRILL COEFFICIENTS AT 0.700 RADIUS TAU(C) = 0.1990 SIGMA = 0.8250

HYDRONAUTICS INC. *** PROPELLER DESIGN PROGRAM 192 *** PROPELLER NUMBER 7694-110-36
 (ARBITRARY CIRCULATION LIFTING LINE *** VERSION 7, FEB. 1975)

1.6000 J CT = 0.3219 CTT = 0.3366 MAX CHORD AT 0.840R 0.0400 T/D AT 0.300R
 0.5092 LAMBDA CP = 0.4063 CPI = 0.3849 ROOT CHORD IS 0.420 0.0210 T/D AT 0.600R
 0.3000 HUB RADIUS KT = 0.3234 KTI = 0.3384 OF MAX CHORD 0.0120 T/D AT 0.900R
 5.0000 BLADES MO = 0.1040 KOI = 0.0905 SIG-T = 2.3800 * T/C 0.0300 T/C MIN
 0.7800 EAR ETA = 0.7922 ETAL = 0.8745 SIG-L = 0.5560 * CL 0.0100 CD AT ROOT
 0.0080 CD AT TIP 0.0080 CD AT TIP
 0.9143 ADVANCE SIGMA 0.3219 CT REQUIRED
 1.0459 CT/CT

N/RD 0.2999 0.3468 0.4749 0.6499 0.8249 0.9531 1.0000
 CIRC 0.0000 0.5000 0.8750 1.0150 0.8150 0.4700 0.0000
 PAIRD 0.0000 0.5014 0.8780 1.0029 0.8330 0.4564 0.0000

AWAKE 0.3400 0.3010 0.2010 0.1100 0.0470 0.0190 0.0100
 IWAKE 0.0210 0.0200 0.0160 0.0110 0.0070 0.0050 0.0020

R/RD	C/D	100*1/D	T/C	UT/2	UA/2V	VT/V	CL	100*CD	CL*C/D	CT	CP	ETAB
0.300	0.1878	4.0000	0.2130	0.1538	0.0795	0.8451	0.0005	1.0000	0.0001	-0.0006	0.0003	-2.8296
0.350	0.2193	3.5267	0.1636	0.1570	0.0954	0.9483	0.4187	0.9857	0.0919	0.0273	0.0309	0.9489
0.400	0.2502	3.2167	0.1285	0.1573	0.1089	1.0492	0.4611	0.9714	0.1154	0.0456	0.0525	0.9561
0.450	0.2805	2.8831	0.1028	0.1552	0.1202	1.1485	0.4457	0.9571	0.1250	0.0633	0.0740	0.9566
0.500	0.3098	2.5868	0.0835	0.1511	0.1292	1.2466	0.4103	0.9429	0.1271	0.0801	0.0952	0.9545
0.550	0.3301	2.3264	0.0688	0.1454	0.1361	1.3436	0.3604	0.9286	0.1245	0.0955	0.1152	0.9507
0.600	0.3448	2.1000	0.0576	0.1386	0.1410	1.4398	0.3259	0.9143	0.1189	0.1088	0.1332	0.9454
0.650	0.3597	1.9052	0.0489	0.1308	0.1439	1.5353	0.2853	0.9000	0.1112	0.1197	0.1485	0.9388
0.700	0.4119	1.7386	0.0422	0.1224	0.1499	1.6303	0.2478	0.8857	0.1021	0.1276	0.1603	0.9305
0.750	0.4304	1.5954	0.0371	0.1136	0.1492	1.7248	0.2137	0.8714	0.0920	0.1319	0.1679	0.9204
0.800	0.4432	1.4681	0.0331	0.1045	0.1418	1.8189	0.1830	0.8571	0.0811	0.1322	0.1704	0.9080
0.850	0.4468	1.3445	0.0301	0.0955	0.1379	1.9126	0.1550	0.8429	0.0693	0.1271	0.1664	0.8926
0.900	0.4334	1.3001	0.0300	0.0865	0.1327	2.0061	0.1292	0.8286	0.0560	0.1147	0.1530	0.8728
0.925	0.4146	1.2743	0.0300	0.0820	0.1296	2.0527	0.1165	0.8214	0.0483	0.1043	0.1408	0.8601
0.950	0.3801	1.1402	0.0300	0.0776	0.1262	2.0993	0.1036	0.8143	0.0394	0.0893	0.1224	0.8443
0.975	0.3115	0.9345	0.0300	0.0732	0.1225	2.1458	0.0894	0.8071	0.0278	0.0661	0.0928	0.8224
0.990	0.2240	0.6720	0.0300	0.0706	0.1202	2.1736	0.0787	0.8029	0.0176	0.0429	0.0616	0.8015
1.000	0.0000	0.0000	0.0300	0.0688	0.1186	2.1922	*****	0.8000	0.0000	0.0001	0.0001	1.0000

R/RD	100*CS	P/100A	LAMBDA(I)	DETAIL	TAN(B)	DETA	TAN(U)	SIG-OP	SIG-T	SIG-L	SIG-I	MARGIN
0.300	0.0013	1.6784	0.5343	60.684	1.7808	49.219	1.1593	1.2802	0.5070	0.0003	0.5072	2.5238
0.350	1.4050	1.7215	0.5480	57.433	1.5656	46.503	1.0539	1.0168	0.3895	0.2329	0.6223	1.6338
0.400	1.9205	1.7584	0.5597	54.449	1.3993	44.126	0.9699	0.8306	0.3059	0.2564	0.5623	1.4770
0.450	2.2599	1.7896	0.5696	51.693	1.2659	42.002	0.9005	0.6931	0.2446	0.2478	0.4924	1.4074
0.500	2.4909	1.8153	0.5778	49.130	1.1557	40.077	0.8414	0.5884	0.1987	0.2281	0.4268	1.3785
0.550	2.6306	1.8359	0.5844	46.737	1.0625	38.312	0.7901	0.5065	0.1638	0.2048	0.3686	1.3740
0.600	2.7150	1.8517	0.5894	44.491	0.9824	36.680	0.7448	0.4411	0.1370	0.1812	0.3181	1.3862
0.650	2.7233	1.8631	0.5930	42.376	0.9124	35.163	0.7044	0.3879	0.1164	0.1586	0.2749	1.4106
0.700	2.6751	1.8702	0.5953	40.379	0.8504	33.744	0.6680	0.3440	0.1004	0.1378	0.2382	1.4440
0.750	2.5612	1.8735	0.5964	38.489	0.7951	32.413	0.6349	0.3073	0.0882	0.1188	0.2070	1.4844
0.800	2.3815	1.8731	0.5962	36.697	0.7453	31.159	0.6047	0.2764	0.0788	0.1017	0.1805	1.5306
0.850	2.1275	1.8694	0.5950	34.994	0.7000	29.976	0.5768	0.2499	0.0716	0.0862	0.1578	1.5838
0.900	1.7792	1.8625	0.5929	33.374	0.6587	28.856	0.5510	0.2272	0.0714	0.0718	0.1432	1.5865
0.925	1.5556	1.8580	0.5914	32.593	0.6394	28.318	0.5389	0.2170	0.0714	0.0648	0.1361	1.5934
0.950	1.2802	1.8528	0.5898	31.832	0.6208	27.794	0.5271	0.2075	0.0714	0.0576	0.1290	1.6083
0.975	0.9111	1.8469	0.5879	31.088	0.6029	27.282	0.5151	0.1986	0.0714	0.0497	0.1210	1.6399
0.990	0.5780	1.8430	0.5867	30.650	0.5926	26.981	0.5091	0.1935	0.0714	0.0438	0.1151	1.6806
1.000	0.0012	1.8403	0.5858	30.362	0.5858	26.783	0.5048	0.1903	0.0714	*****	*****	0.0000

SAW-BURKILL COEFFICIENTS AT 0.700 RADIUS TAU(C) = 0.2187 SIGMA = 0.3095

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Lifting Line Program Output

The lifting line calculations were carried out using the HYDRONAUTICS, Incorporated computer program PR 192, Version 7. Besides the Lerbs theory, this program also carries out calculations for the basic blade geometry and provides information on cavitation inception. An explanation of the contents and notations on the output page is presented below.

The propeller number is listed in the title block along with the program number, which version of the program, and the date of the last revision. This write-up applies to Version 7, revised February 1975.

Input parameters are listed at the top of the output page. The first column of five items contains:

J: The advance ratio = V/nD where V is the ship velocity ($V = V_s$), n is rotative speed in rps and D is the diameter.

LAMBDA: $LAMBDA = J/\pi = V/\pi nD$. LAMBDA is the ratio of tip speed to ship speed or $\tan(\beta)$ at the tip, where β is the inflow angle based on ship speed.

HUB RADIUS: This is the hub radius expressed as a fraction of the total radius

BLADES: The number of blades on the propeller

EAR: The expanded blade area ratio for all the blades on the propeller

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The second column of five items:

CT: Thrust loading coefficient =
$$\frac{T}{\frac{1}{2}\rho V^2 \left(\frac{\pi}{4} D^2 \right)}$$

CT = KT (8/(\pi J^2)) where T is the thrust in lbs.

CP: Power loading coefficient =
$$\frac{P}{\frac{1}{2}\rho V^2 \left(\frac{\pi}{4} D^2 \right) V \cdot D}$$

CP = KW (16/J^3) where P is the input power in foot pounds per second

KT: Thrust coefficient =
$$\frac{T}{\rho n^2 D^4} = KT = CT(\pi J^2/8)$$

KQ: Torque coefficient =
$$\frac{Q}{\rho n^2 D^5} = KQ = CP(J^3/16)$$

ETA: ETA (η) is the overall propeller efficiency

$$ETA = \frac{CT}{CP} = \frac{KT}{KW} \frac{J}{2\pi}$$
 . This is the efficiency of the blades only and does not include hub losses due to cavitation.

This efficiency (η) is related to open water efficient (η_o) by $\eta = \eta_o \eta_{rr} / (1-w)$, where w = mean volumetric wake. P.C., therefore, equals $\eta(1-t)$.

The third column of five items corresponds to the previous column except that they refer to the "ideal" values. That is, the values associated with the potential flow, escluding losses from skin friction. (ETAI) therefore represents the "ideal" efficiency and is a measure of induced losses. The difference between (ETA) and (ETAI) is a measure of losses due to blade friction drag.

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The fourth column presents the radial location of the maximum blade chord as a fraction of the propeller radius, and the ratio of blade root chord to maximum chord. The last two items in this column are the equations for obtaining the incipient cavitation number due to thickness (SIG-T) and loading (SIG-L). The constants in these equations are read as input data.

The last column of 9 lines contains the input thickness diameter ratios and the radii at which they occur along with the minimum thickness chord ratio. These are used to provide a curve fit to the required thickness distribution. The next two items are the input drag coefficients at the blade root and tip. A linear interpolation between these values is used to obtain the drag coefficients at all other radii. The (ADVANCE SIGMA) is the reference cavitation number based on the ship velocity, (CT REQUIRED) is the specified thrust coefficient. An iteration procedure is required in the program to develop the required thrust. Therefore (CT REQUIRED) should be compared with the final (CT), Column 2, to assure that the final thrust is adequately close to the required thrust. The ratio (CTI/CT) is a measure of the additional ideal thrust the propeller must produce to overcome its own frictional losses.

The first row labeled (R/R0) is the nondimensional radii at which the form of the circulation distribution has been specified. The row labeled (CIRCG) is the input values of circulation distribution at the corresponding radii. If faired data has been required, a third row containing the faired circulation distribution is printed and labeled (FAIRED). If unfaired output is

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requested this row is omitted. The two following rows of input, labeled (AWAKE) and (TWAKE), are, respectively, the mean values of nondimensional radii.

The following two sets of data are the computed output. These data have been rounded off, not truncated, to the number of decimal places provided.

- R/RO: Nondimensional radii specified for output on the first input data card. Each item in a given row pertains to the radii R/RO listed at the left of the page.
- C/D: Blade chord-diameter ratio.
- 100*T/D: One hundred times the thickness diameter ratio.
- T/C: Thickness chord ratio.
- UT/2V: Tangential induced velocity at lifting line nondimensionalized with respect to ship velocity.
- UA/2V: Axial induced velocity at lifting line nondimensionalized with respect to ship velocity.
- VT/V: Ratio of total velocity at blade (including induced velocities) to ship velocity.
- CL: Section lift coefficient based on VT. Note that CL is undefined at the blade tip where both lift and chord go to zero.
- 100*CD: One hundred times the section drag coefficient based on VT.

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CL*C/D: Radial load parameter. This is like a lift coefficient but is based on diameter instead of blade chord. It is therefore independent of the blade planform.

CT: Differential thrust coefficient per blade. This value, integrated over the length of the blade and multiplied by the number of blades will yield the total CT listed in column two at the top of the page.

CP: Differential power coefficient per blade. This value, integrated over the length of the blade and multiplied by the number of blades will yield the total CP listed in column two at the top of the page.

ETAB: Blading efficiency (η_{BLADE}). This is the ratio of useful work done on the fluid to the total work input. It is useful in selecting the blade planform.

$$\eta_{\text{BLADE}} = \frac{1 - (CD/CL) \tan(\beta_1)}{1 + (CD/CL)/\tan(\beta_1)}$$

η_{BLADE} is undefined at the blade tip. The tip value can be obtained by extrapolating the other values to the tip. η_{BLADE} is usually negative at the root since the root section usually has a net drag (CT is negative at the root).

100*GS: One hundred times the nondimensional circulation. $GS = \text{Circulation}/\pi DV$

P(I)DIA: Hydrodynamic (including induced flow) pitch-diameter ratio (hydrodynamic advance ratio).

LAMBDA(I): Hydrodynamic (including induced flow) pitch-circumference ratio.

$$\lambda_1 = (\text{Pitch-diameter ratio})/\pi = (R/RO)\tan(\beta_1).$$

BETA(I): Hydrodynamic advance angle in degrees, β_1 .
(Including induced flow).

TAN(BI): Tangent of hydrodynamic advance angle, $\tan(\beta_1)$. This is the ratio of tangential velocity to axial velocity at each blade section.

$$\tan(\beta_1) = \lambda_1/(R/RO).$$

BETA: Geometric pitch angle in degrees, β .

TAN(B): Tangent of geometric pitch angle
 $\tan(B) = \lambda/R/RO$.

SIG-OP: Operating cavitation number (σ_{OP}) at each radius based on ADVANCE SIGMA and VT.

SIG-T: Incipient cavitation number due to thickness,
 $\sigma_1(\text{thickness})$.

SIG-L: Incipient cavitation number due to loading,
 $\sigma_1(\text{loading})$.

SIG-I: Total section incipient cavitation number, σ_1 .
 $\sigma_1 = \sigma_1(\text{thickness}) + \sigma_1(\text{loading})$.

MARGIN: This is the ratio of σ_{OP} to σ_1 and represents the V^2 margin each section has over cavitation inception.

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The last line of output has the Gawn-Burrill coefficients computed at the 0.7 radius.

TACU(C): The "mean" lift coefficient

$$\tau_c = \frac{T}{\frac{1}{2}\rho V_R A_P}$$

SIGMA: Local cavitation number

$$\sigma_R = (P_O - P_V) / \frac{1}{2}\rho V_R^2$$

where

$$V_R = V \sqrt{1 + (0.7\pi/J)^2}$$

V = Ship velocity

A_P: Approximate projected blade area

$$A_P = \text{EAR} (1.067 - 0.229 P/D) D^2 (\pi/4)$$

P_O = Static pressure

P_V = Vapor pressure